

## Table of Contents

page

**Summary****Introduction****Methodology and Master Data Table****Data Quality****Schoeller Diagrams****Piper Diagrams****Chemical Controls on Na-HCO<sub>3</sub> Waters****Chemical Controls on Ca-Mg-Mixed Waters****Chemical Controls on Ca-Mg-HCO<sub>3</sub> Waters****Mixing of Waters****Identification of Carbonate Producing Zones****TCE Distribution****Water Table Trends****Discussion, Conclusions and Recommendations****References**

## List of Figures

- Figure 1. Geology of site area (Buckwalter, 1959).
- Figure 2. Comparison of total anions versus total cations for total EPA Hereford data.
- Figure 3. Percent difference versus anions plus cations for EPA Hereford data.
- Figure 4.  $\text{HCO}_3$  versus pH as measured by Weston/REAC.
- Figure 5.  $\text{HCO}_3$  versus pH as measured by EPA.
- Figure 6. Schoeller plot for Na- $\text{HCO}_3$  water
- Figure 7. Schoeller plot for Ca-Mg-Mixed water.
- Figure 8. Schoeller plot for Ca-Mg- $\text{HCO}_3$  water. Concentration scale to 3.0 meq/L.
- Figure 9. Schoeller plot for Ca-Mg- $\text{HCO}_3$  water. Concentration scale changed to 1.5 meq/L.
- Figure 10. Schoeller plot for Ca-Mg- $\text{HCO}_3$  with NaCl.
- Figure 11. Piper diagram for Na- $\text{HCO}_3$  water.
- Figure 12. Piper diagram for Ca-Mg-Mixed water.
- Figure 13. Piper diagram for Ca-Mg- $\text{HCO}_3$  water.
- Figure 14. Na versus  $\text{HCO}_3$  for Na- $\text{HCO}_3$  water.
- Figure 15.  $\text{HCO}_3$  versus  $\text{SO}_4$  for Na- $\text{HCO}_3$  water.
- Figure 16. pH versus  $\text{SO}_4$  for Na- $\text{HCO}_3$  water.
- Figure 17. Na versus  $\text{SiO}_2$  for Na- $\text{HCO}_3$  water.
- Figure 18. pH versus  $\text{HCO}_3$  for Na- $\text{HCO}_3$  water.
- Figure 19. Ca versus  $\text{SiO}_2$  for Na- $\text{HCO}_3$  water.
- Figure 20. Mg versus  $\text{SiO}_2$  for Na- $\text{HCO}_3$  water.
- Figure 21. Ca versus  $\text{SiO}_2$  for Ca-Mg-Mixed water.
- Figure 22. Mg versus  $\text{SiO}_2$  for Ca-Mg-Mixed water.
- Figure 23. Na versus  $\text{SiO}_2$  for Ca-Mg-Mixed water.
- Figure 24.  $\text{HCO}_3$  versus  $\text{SiO}_2$  for Ca-Mg-Mixed water.
- Figure 25. Ca versus Mg for Ca-Mg-Mixed water.
- Figure 26. Na versus  $\text{HCO}_3$  for Ca-Mg-Mixed water.
- Figure 27.  $\text{HCO}_3$  versus  $\text{SO}_4$  for Ca-Mg-Mixed water.
- Figure 28. Ca versus Mg for Ca-Mg- $\text{HCO}_3$  waters.
- Figure 29. Ca versus  $\text{HCO}_3$  for Ca-Mg- $\text{HCO}_3$  waters.
- Figure 30. Mg versus  $\text{HCO}_3$  for Ca-Mg- $\text{HCO}_3$  waters.
- Figure 31. Na versus  $\text{SiO}_2$  for Ca-Mg- $\text{HCO}_3$  waters.
- Figure 32.  $\text{HCO}_3$  versus  $\text{SO}_4$  for Ca-Mg- $\text{HCO}_3$  waters.
- Figure 33. Na versus TDS for Na- $\text{HCO}_3$  and Ca-Mg-Mixed waters.
- Figure 34.  $\text{HCO}_3$  vs  $\text{SiO}_2$  for Na- $\text{HCO}_3$  and Ca-Mg-Mixed waters.

Figure 35. Na versus SiO<sub>2</sub> for Na-HCO<sub>3</sub> and Ca-Mg-Mixed waters.  
 Figure 36. TDS vs Mg for flow from Na-HCO<sub>3</sub> and Ca-Mg-Mixed waters to Ca-Mg-HCO<sub>3</sub> waters.  
 Figure 37. TDS versus Ca for flow from Na-HCO<sub>3</sub> and Ca-Mg-Mixed waters to Ca-Mg-HCO<sub>3</sub> waters.  
 Figure 38. TDS versus SO<sub>4</sub> for flow from Na-HCO<sub>3</sub> and Ca-Mg-Mixed waters to Ca-Mg-HCO<sub>3</sub> waters.  
 Figure 39. TDS versus Na for flow from Na-HCO<sub>3</sub> and Ca-Mg-Mixed waters to Ca-Mg-HCO<sub>3</sub> waters.  
 Figure 40. TDS versus HCO<sub>3</sub> for flow from Na-HCO<sub>3</sub> and Ca-Mg-Mixed waters to Ca-Mg-HCO<sub>3</sub> waters.  
 Figure 41. TCE concentrations (1988) versus TDS for Ca-Mg-Mixed, Na-HCO<sub>3</sub>, and Ca-Mg-HCO<sub>3</sub> waters.  
 Figure 42. TCE concentrations (1988) versus HCO<sub>3</sub> for Ca-Mg-Mixed, Na-HCO<sub>3</sub>, and Ca-Mg-HCO<sub>3</sub> waters.  
 Figure 43. TCE versus HCO<sub>3</sub> for Na-HCO<sub>3</sub> and Ca-Mg-Mixed waters. TCE scale to 20,000 ppb.  
 Figure 44. TCE versus HCO<sub>3</sub> for Na-HCO<sub>3</sub> and Ca-Mg-HCO<sub>3</sub> waters. TCE scale to 100 ppb.  
 Figure 45. Well elevation versus water table for Na-HCO<sub>3</sub>, Ca-Mg-Mixed and Ca-Mg-HCO<sub>3</sub> waters.  
 Figure 46. Depth to water (7/88) versus well elevation for Na-HCO<sub>3</sub>, Ca-Mg-Mixed and Ca-Mg-HCO<sub>3</sub> waters.

### Tables

Table 1. Master data table.  
 Table 2. Data table of duplicate analyses.  
 Table 3. TCE concentrations in descending order with chemical composition and limited well data.  
 Table 4. Water level data trends for monitoring well clusters

## Summary

Ground waters in the Hereford site, Berks County, Pennsylvania, area have been contaminated by surface disposal of TCE on the Crossley Farm, located on Blackhead Hill. TCE ground-water contamination occurs in different rock types and shows up at appreciable distance (almost 2 miles away) from the suspected source. The contamination is not contained in a discrete definable plume as typically occurs in a porous media aquifer. The significant topographic relief, complex geology and possible fracture and fault zones has caused this extensive and complex spread of TCE.

Three different water chemistries, based on Schoeller diagrams, have been observed. A Na-HCO<sub>3</sub> water occurs on Blackhead Hill from wells producing from Hardyston quartzite and overburden, the Byram gneiss and gneissic sapprolite. A Ca-Mg-Mixed water occurs in domestic water wells and a few monitoring wells in the valley at the base of Blackhead Hill. These wells also produce from the Byram gneiss, the Hardyston quartzite and overburden material. It is perplexing that the same rock types have different water chemistry and conversely that different rock types have similar water chemistry. The third water chemistry group is a Ca-Mg-HCO<sub>3</sub> water that is produced predominantly from the Tomstown limestones. Each water chemistry group appears to be internally consistent, that is, a similar geochemical process can explain the evolution of the water chemistry within each group.

The chemical composition of each water type has also been used to evaluate whether one type of water has evolved from another water type that was hydrologically updip. Logically waters

(Na-HCO<sub>3</sub>) from Blackhead Hill should flow down the topographic and water table gradient to lower elevations and be evident in the chemistry of the Ca-Mg-Mixed and Ca-Mg-HCO<sub>3</sub> waters. The Ca-Mg-Mixed waters, however, cannot have evolved from the Na-HCO<sub>3</sub> waters. The TDS of the Ca-Mg-Mixed waters is less than the TDS of the Na-HCO<sub>3</sub> waters as well as having different chemical trends. With this chemistry it is hard to explain the movement of TCE from Blackhead Hill to surrounding wells at lower elevations. One option is that TCE may be moving as a separate phase and not part of the regional ground-water flow. A second option is that there are additional sources of contamination off Blackhead Hill. A third option is that well construction may have altered the water chemistry in the Na-HCO<sub>3</sub> well waters.

The water chemistry of the Ca-Mg-HCO<sub>3</sub> waters strongly suggests that waters could have flowed from the Ca-Mg-Mixed waters into the carbonates. The chemistry does not support as well the flow of water from the Na-HCO<sub>3</sub> water to the Ca-Mg-HCO<sub>3</sub>. Establishing the flow system from the Byram gneiss and Hardyston quartzite to the Tomstown carbonate indicates that TCE contamination can migrate to the carbonate aquifers.

The hydrogeologic setting for contaminant migration is a mixed fractured crystalline bedrock/ limestone karst system. The erratic distribution of TCE within the limestone and nonlimestone wells argues for fracture flow in the nonlimestone formations and karstic flow within the limestones. The strong topographic relief may result in relatively small flow systems. However, if the Hereford site is underlain by permeable Paleozoic carbonates, a larger flow system

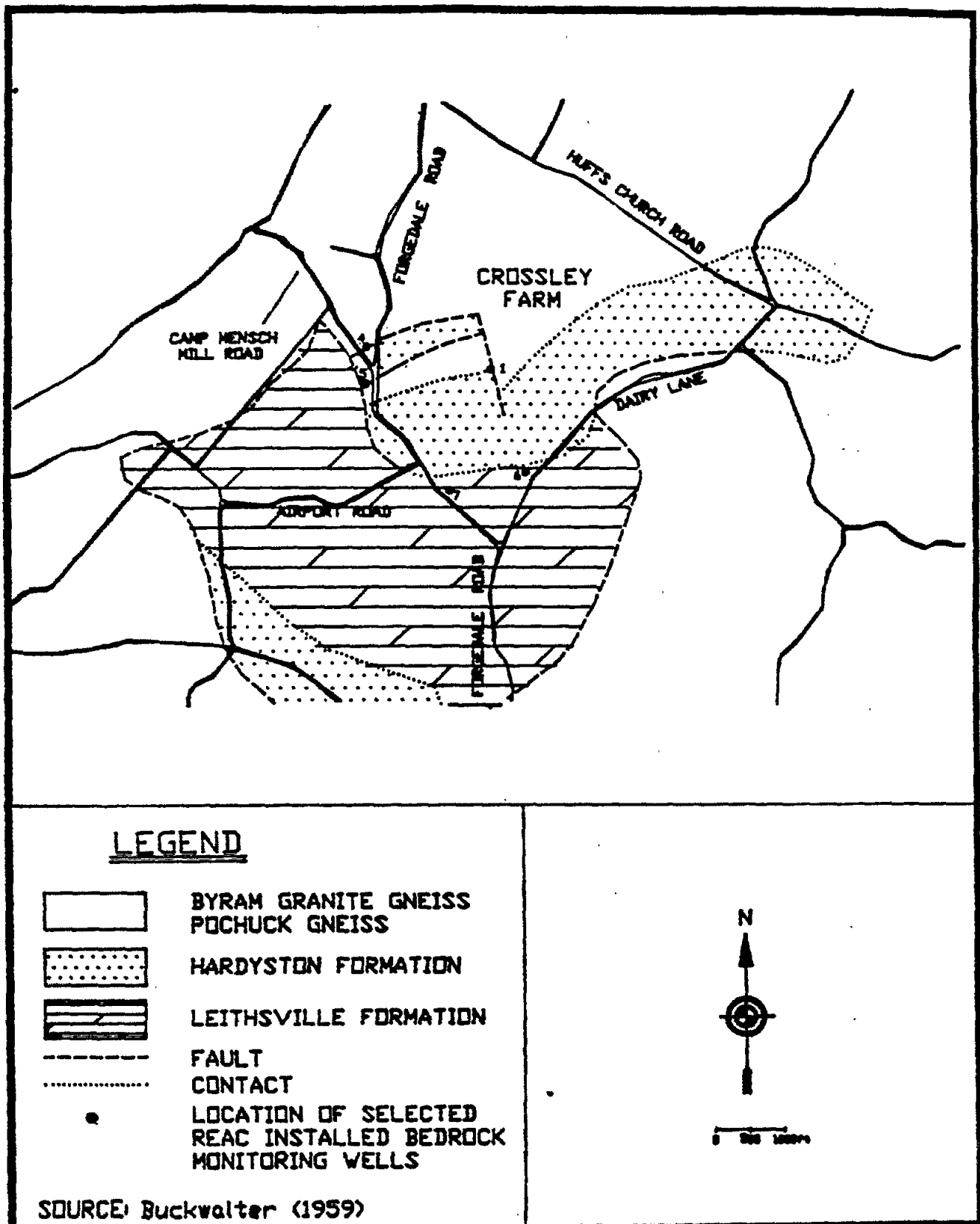
may occur and the areal extent of contamination may be larger. Future contamination characterization studies and remediation strategies need to be oriented toward fracture/karst approaches.

## Introduction

*Hereford Township*  
The ~~Town of Hereford~~ site is an area of soil and ground-water trichlorethylene (TCE) contamination around Blackhead Hill in the municipality of Hereford, ~~Berks~~ *Township* County, Pennsylvania. A detailed investigation has been conducted by Weston/IT to identify the extent of contamination, the direction of movement and methods of remediation. Weston/IT concluded in their final report that the source of the contamination is predominantly on Blackhead Hill, the geology of the site is very complex, TCE transport away from the contamination source was via a complex system of fractures, remediation by excavating the waste sources would be difficult, and the benefits of in situ remediation were limited. The history of site activities, the area geology, summary of hydrogeologic investigations before the Weston/IT studies as well as the investigations conducted by Weston/IT are contained in their final report, "Regional Hydrogeologic Investigation, Town of Hereford Site, Berks County, Pennsylvania", EPA Contract No. 68-03-3482.

The site's geology and hydrogeology is complex and makes the interpretation of TCE source and pathways of migration difficult. Buckwalter (1959) shows a complex geologic setting of Precambrian gneisses topographically higher than Paleozoic carbonates (Cambro-Ordovician carbonates) and sandstones (Cambrian Hardyston sandstones and quartzites) (fig. 1) and suggested two hypotheses to explain this anomalous stratigraphic setting (Buckwalter, 1962): 1) Precambrian rocks were thrust over Paleozoic rocks, or 2) the

FIGURE 1  
PROJECT AREA GEOLOGY



AR300089



exposed Paleozoic carbonates in Dale Valley are result of down faulting into a deep syncline. In regards to ground-water flow and contaminant transport in this complex geologic setting, there are three important controls, 1) the complex geology, 2) the faulting and fracturing of the bedrock, and the high topographic relief that has developed in this complex geologic setting. The complex distribution of lithologies may control directions of ground-water flow.

Contaminant transport may be compartmentalized within distinct lithologic units (e.g., ground water flow and TCE transport that started as a contaminant spill on the outcrop of the Hardyston sandstones may be restricted to flow within the Hardyston and not contaminate ground waters in the Byram gnesiss). If the hypothesis of thrusting is correct, the area may be underlain by Paleozoic carbonates at depth and represent an undeveloped and uncontaminated water supply. The area has also been extensively faulted and fractured. Fracturing may permit flow from one geologic block into another. If this is the case, lithologic controls may not be as important. Over 200 ft of topographic relief (from the top of Blackhead Hill to Perkiomen Creek) add to the complex hydrogeologic setting. The water table <sup>typically</sup> mimics the topography. A complex topography therefore results in complex ground-water flow directions.

To better understand the complex hydrogeology at the site, EPA decided that a investigation of the natural chemical composition of the ground waters at the site might provide additional insight on the migration of TCE. A prime benefit in studying the water chemistry is to use the chemistry as a tracer of ground water

movement. Tracers can be artificial (e.g. TCE) or natural. If the exact source of contaminant spillage at the site is known, then artificial tracers such as TCE can be used to identify flow path. Natural water chemistry generally does not identify points of contamination but rock types through which the water has moved. Natural composition of the ground waters is controlled by the mineralogy of the rocks through which it presently flowing. In addition the water chemistry may also indicate flow through rocks of different lithologies earlier in its flow history, that is the water chemistry contains a memory of its earlier flow history. For domestic wells in complex geologic settings the producing zone and its lithology may not be known. Water chemistry also can be used to identify what zone a well is screened in and where that water is coming from. (A well's <sup>potential?</sup> for contamination can be better known.) Huh?

The water chemistry from the Hereford site has been analyzed for the following goals: 1) Determine whether ground waters from the different lithologies (Precambrian gneiss, Hardyston sandstone, Tomstown limestone and overburden materials (gneissic saprolite and soils developed on Hardyston formation) have distinctive chemical compositions such that waters from these lithologies can be distinguished. 2) Determine whether the chemical composition of ground waters from one rock type indicates previous flow through another rock type, and therefore identify its flow paths. For example, did ground water in the Tomstown limestone previously flow through the gneisses or the Hardyston sandstone? 3) Determine the dominant producing interval for domestic wells where minimal well

data are available. Wells producing from carbonates appear less susceptible to TCE contamination than wells in gneiss or sandstone.

The goals have been investigated through the following steps:

- 1) Compile all available data; 2) Review data quality; 3) Identify different chemical compositions through Schoeller diagrams; 4) Plot water chemistry on Piper diagrams to see if there is concurrence with Schoeller diagrams; 5) Investigate the water chemistry of the different water types to understand lithologic controls on water chemistry and make sure there is internal consistency of water chemistry within each chemical grouping; 6) Compare water chemistry groupings to determine whether there is evidence of flow from one water type to another; 7) Investigate the distribution of TCE with different water types; 8) review water table trends (hydrologic data) to see if the physical hydrologic setting concurs with hydrochemical interpretations; and 9) Summarize.

MAP  
Formation water & compare  
1. 11.1.74

## Methodology and Master Data Table

This hydrochemical investigation was conducted by Dr. Charles W. Kreidler, the University of Texas at Austin. Data used in this report are included in the Master Data Table (Table 1). This table includes all hydrochemical and hydrologic data. Dr. Kreidler visited the Hereford site area in the spring of 1988 with Dr. Randal Charbeneau, The University of Texas at Austin, Martin Mortensen, U.S. E.P.A./ERB Region 3, Frank Fendler, IT, Corporation, and Dr. Steve Schmelling, U.S. E.P.A., Robert S. Kerr Laboratory. Dr. Steve Schmelling collected the water samples used for chemical interpretation from May 9 to May 11, 1988. Three casing volumes of water were purged before a sample was collected. Samples for metal analysis were filtered and fixed in the field. Alkalinity was titrated at the motel after sampling. Samples were then shipped express to Robert S. Kerr Laboratory. Chemical analyses were made by U.S. E.P.A. Robert S. Kerr Laboratory.  $\text{HCO}_3$  was analyzed in the laboratory. The pH (EPA) measurements made by Steve Schmelling were made with pH paper. The pH measurements made by Weston/IT personnel were done with a pH meter during well purging before sample collection. TCE measurements used in this report were made by Weston/IT personnel and reported in final report of Regional Hydrogeologic Investigation, Town of Hereford Site, Berks County, Pennsylvania. Well locations are based on the well location map in "Regional Hydrogeologic Investigation, <sup>Hereford Township</sup> ~~Town of Hereford~~ Site, Berks County, Pennsylvania". Additional comments on water chemistry are included under the section on Data Quality and Explanation for the

master data table. Data for well elevation, well depth, depth to water (DTW) and water table elevation (WT) are from the final report of Regional Hydrogeologic Investigation, <sup>Hereford Township</sup> ~~Town of Hereford~~ Site, Berks County, Pennsylvania. Surface geology at well locations is based on comparison of the geologic map from Buckwalter (1959) and the well location map in the final report of Regional Hydrogeologic Investigation, ~~Town of Hereford Site~~, Berks County, Pennsylvania.

*Hereford Township*

## Master Data Table

EPA lab no.	location	NO3 (mg/L)	NH3 (mg/L)	SO4 (mg/L)	Cl (mg/L)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)
1	7831	0.80	0.00	8.1	5.0	4.30	0.80	33.00	18.00
2	7830	1.00	0.00	0.0	5.5	3.00	1.40	26.00	15.00
3	7840	0.85	0.00	7.5	3.0	1.89	1.30	25.00	15.00
4	7835	2.30	0.00	21.0	8.0	3.90	0.70	22.00	8.40
5	7853	4.90	0.00	18.0	17.0	10.00	20.00	15.00	11.00
6	7854	1.70	0.00	14.0	4.0	4.20	0.80	29.00	15.00
7	7862	0.70	0.00	4.0	2.0	1.90	0.90	13.00	7.40
8	7864	2.20	0.00	14.0	18.0	6.70	1.70	21.00	11.00
9	7846	2.10	0.00	7.5	4.0	1.50	1.60	25.00	15.00
10	7848	1.20	0.00	11.3	5.0	2.90	1.40	29.00	17.00
11	7826	0.90	0.10	9.1	5.0	2.80	2.60	18.00	13.00
12	7859	2.10	0.00	6.0	48.0	22.00	4.30	32.00	20.00
13	7833	6.80	0.00	13.0	11.0	6.40	1.90	11.00	4.50
14	7836	3.10	0.00	20.0	4.5	5.00	0.80	9.70	3.40
15	7844	1.70	0.00	8.3	2.0	1.20	0.70	2.90	1.80
16	7847	9.20	0.00	8.6	8.0	6.70	1.00	14.00	5.90
17	7834	3.20	0.00	10.0	11.0	8.10	1.50	8.20	3.80
18	7851	0.70	0.00	2.0	2.0	1.50	2.00	0.70	2.20
19	7832	1.40	0.00	3.7	3.5	2.60	0.90	2.00	0.70
20	7850	0.70	0.00	8.3	3.0	1.70	1.00	2.40	1.60
21	7849	1.10	0.00	16.1	3.0	5.40	1.20	7.70	2.50
22	7852	1.20	0.00	20.0	3.0	3.90	0.60	8.70	3.50
23	7860	2.00	0.00	5.0	27.0	12.00	1.40	6.00	2.50
24	7824	5.30	0.00	4.3	4.0	5.80	3.70	4.20	1.60
25	7863	0.65	0.35	8.0	2.0	2.90	3.20	4.20	1.50
26	7843	0.75	0.00	3.7	2.0	2.40	1.40	2.00	0.90
27	7845	4.00	0.00	14.0	8.0	9.80	4.20	12.00	4.40
28	7842	0.55	0.00	15.0	5.0	9.10	5.00	8.10	2.50
29	7827	0.90	0.00	6.2	3.0	4.80	1.80	3.60	1.30
30	7829	2.20	0.00	4.3	3.5	5.80	2.90	7.70	1.40
31	7861	3.20	0.50	3.0	6.0	7.90	7.30	4.80	2.40
32	7839	6.00	0.00	39.0	13.0	21.00	48.00	9.00	0.90
33	7837	3.90	0.00	36.0	7.5	4.10	0.90	26.00	11.00
34	7841	0.30	0.00	13.0	3.0	11.00	4.20	3.90	1.30
35	7857	0.40	0.00	19.0	5.0	16.00	10.00	12.00	2.50

date.

AR300095

## Master Data Table

	Fe (mg/L)	SiO <sub>2</sub> (mg/L)	Alk (mg/L)	HCO <sub>3</sub> (mg/L)	Conductivity	pH (Weston)	pH (EPA)	TCE(ug/L)(87)	TCE(ug/L) (88)	T (C)	TDS (mg/L)
1	0.0	8.76	150	182.88			6.0	0	0		261.6
2	0.0	5.88	120	146.30			6.0	366	586		204.1
3	0.0	4.27	112	136.55			6.0		0		195.4
4	0.0	8.05	72	87.78			5.0	489	4		162.1
5	0.0	2.23	64	78.03			6.0	6	0		176.2
6	0.0	7.05	128	156.05			6.0	0	1414		231.8
7	0.0	4.00	66	80.46	95	7.9	6.0		2047		114.4
8	0.0	2.66	76	92.66	115	8.2	6.0		35	10.0	169.9
9	0.0	3.09	114	138.99	165	8.1	7.0		32	13.0	198.8
10	0.0	4.05	134	163.37	200	5.7	6.0		24	15.5	235.2
11	0.0	1.20	82	99.97		7.7	6.0		259		152.7
12	0.0	3.37	136	165.81	315	6.3	6.0		0	12.5	303.6
13	0.0	6.51	16	19.51			5.0		0		80.6
14	0.0	6.72	20	24.38			5.0	2	0		77.6
15	0.0	2.10	6	7.31			5.0	2	2		28.0
16	0.0	8.38	32	39.01			5.2	0	771		100.8
17	0.0	9.90	20	24.38			5.0		0		80.1
18	0.0	4.57	14	17.07			5.0		0		32.7
19	0.0	3.70	8	9.75			5.0		7221		28.2
20	0.0	2.28	8	9.75			5.0		1830		30.7
21	0.0	7.25	24	29.26			5.2	0	26		73.5
22	0.0	7.09	20	24.38			5.0		0		72.4
23	0.0	3.93	12	14.63		5.4	6.2		1960		74.5
24	0.0	2.87	12	14.63	65	4.5	5.0		73		46.4
25	0.4	3.59	26	31.69	50	8.8	5.2		4064	13.0	58.5
26	0.0	2.86	12	14.63	30	5.1	5.0		0	12.0	30.6
27	0.0	7.65	46	54.08	110	5.8	5.2		5748		118.1
28	0.1	5.66	38	46.33	100	5.6	5.2		6845		97.3
29	0.0	4.92	18	21.94		4.5	5.0		1027		48.5
30	0.0	7.15	30	36.57	60	9.3	5.0		19630		71.5
31	0.5	5.47	32	39.01	80	5.3	6.0		0	12.0	80.1
32	0.0	5.48	64	78.03		8.2	7.0		3	12.5	220.4
33	0.0	6.29	72	87.78		7.7	6.0		4	14.0	183.5
34	0.2	3.80	38	46.33		5.6	5.5		117		87.0
35	0.0	2.81	62	75.59		6.5	6.0		88		143.3

AR300096

Master Data Table

	NO3 (meq/L)	SO4 (meq/L)	Cl (meq/L)	HCO3 (meq/L)	Na (meq/L)	K (meq/L)	Ca (meq/L)	Mg (meq/L)	An (meq/L)	Cat (meq/L)	An-Cat
1	0.06	0.17	0.14	3.00	0.19	0.02	1.65	1.48	3.36	3.34	0.03
2	0.07	0.00	0.16	2.40	0.13	0.04	1.30	1.23	2.62	2.70	-0.07
3	0.06	0.16	0.08	2.24	0.08	0.03	1.25	1.23	2.54	2.60	-0.06
4	0.16	0.44	0.23	1.44	0.17	0.02	1.10	0.69	2.27	1.98	0.29
5	0.35	0.37	0.48	1.28	0.44	0.51	0.75	0.90	2.48	2.60	-0.12
6	0.12	0.29	0.11	2.56	0.18	0.02	1.45	1.23	3.08	2.88	0.20
7	0.05	0.08	0.06	1.32	0.08	0.02	0.65	0.61	1.51	1.36	0.15
8	0.16	0.29	0.51	1.52	0.29	0.04	1.05	0.90	2.47	2.29	0.19
9	0.15	0.16	0.11	2.28	0.07	0.04	1.25	1.23	2.70	2.59	0.11
10	0.09	0.24	0.14	2.68	0.13	0.04	1.45	1.40	3.14	3.01	0.13
11	0.06	0.19	0.14	1.64	0.12	0.07	0.90	1.07	2.03	2.16	-0.12
12	0.15	0.12	1.35	2.72	0.96	0.11	1.60	1.65	4.35	4.31	0.04
13	0.49	0.27	0.31	0.32	0.28	0.05	0.55	0.37	1.39	1.25	0.14
14	0.22	0.42	0.13	0.40	0.22	0.02	0.48	0.28	1.16	1.00	0.16
15	0.12	0.17	0.06	0.12	0.05	0.02	0.14	0.15	0.47	0.36	0.11
16	0.66	0.18	0.23	0.64	0.29	0.03	0.70	0.49	1.70	1.50	0.20
17	0.23	0.21	0.31	0.40	0.35	0.04	0.41	0.31	1.15	1.11	0.03
18	0.05	0.04	0.06	0.28	0.07	0.05	0.03	0.18	0.43	0.33	0.10
19	0.10	0.08	0.10	0.16	0.11	0.02	0.10	0.06	0.44	0.29	0.14
20	0.05	0.17	0.08	0.16	0.07	0.03	0.12	0.13	0.47	0.35	0.12
21	0.08	0.33	0.08	0.48	0.23	0.03	0.38	0.21	0.98	0.86	0.12
22	0.09	0.42	0.08	0.40	0.17	0.02	0.43	0.29	0.99	0.91	0.08
23	0.14	0.10	0.76	0.24	0.52	0.04	0.30	0.21	1.25	1.06	0.19
24	0.38	0.09	0.11	0.24	0.25	0.09	0.21	0.13	0.82	0.69	0.13
25	0.05	0.17	0.06	0.52	0.13	0.08	0.21	0.12	0.79	0.54	0.25
26	0.05	0.08	0.06	0.24	0.10	0.04	0.10	0.07	0.43	0.31	0.11
27	0.29	0.29	0.23	0.89	0.43	0.11	0.60	0.36	1.69	1.49	0.19
28	0.04	0.31	0.14	0.76	0.40	0.13	0.40	0.21	1.25	1.13	0.12
29	0.06	0.13	0.08	0.36	0.21	0.05	0.18	0.11	0.64	0.54	0.10
30	0.16	0.09	0.10	0.60	0.25	0.07	0.38	0.12	0.94	0.83	0.12
31	0.23	0.06	0.17	0.64	0.34	0.19	0.24	0.20	1.10	0.97	0.13
32	0.43	0.81	0.37	1.28	0.91	1.23	0.45	0.07	2.89	2.66	0.22
33	0.28	0.75	0.21	1.44	0.18	0.02	1.30	0.90	2.68	2.40	0.27
34	0.02	0.27	0.08	0.76	0.48	0.11	0.19	0.11	1.14	0.89	0.25
35	0.03	0.40	0.14	1.24	0.70	0.26	0.60	0.21	1.80	1.76	0.05

AR300097



## Master Data Table

An+Cat	Per dif	Chemical Group	Surf. Geol.	well elev. (ft)	Well depth (ft)	DTW(ft)(6/88)	DTW(ft)(7/88)	WT(ft)(6/88)	WT(ft) (7/88)
1	6.70	Ca-Mg-HCO3	OCc	650	172	44	49	625	620
2	5.32	Ca-Mg-HCO3	Chm, OCc	669	300	42	46	593	589
3	5.14	Ca-Mg-HCO3	OCc	635					
4	4.24	Ca-Mg-HCO3	bp	850					
5	5.08	Ca-Mg-HCO3	OCc	643	85				
6	5.97	Ca-Mg-HCO3	OCc	681	237	58	62	623	618
7	2.87	Ca-Mg-HCO3	Chm	646	101	49	53	597	593
8	4.76	Ca-Mg-HCO3	OCc	644	124	47	52	596	591
9	5.28	Ca-Mg-HCO3	OCc	644	95	48	52	596	592
10	6.15	Ca-Mg-HCO3	OCc	600	123	14	16	586	583
11	4.19	Ca-Mg-HCO3	OCc	645	56	48	52	597	593
12	8.66	CaMgNaClHCO3	OCc	906	104	1	20	905	887
13	2.63	Ca-Mg-Mixed	bp	779	202	16	19	763	760
14	2.17	Ca-Mg-Mixed	bp	657	58	7	21	651	636
15	0.83	Ca-Mg-Mixed	Chl	732					
16	3.20	Ca-Mg-Mixed	bp	745	220	36	39	710	707
17	2.26	Ca-Mg-Mixed	Chm	620	85				
18	0.76	Ca-Mg-Mixed	OCc	686	257	54	59	632	627
19	0.73	Ca-Mg-Mixed	Chm	689	125	37	48	652	620
20	0.82	Ca-Mg-Mixed	Chl	700	125	44	49	655	651
21	1.83	Ca-Mg-Mixed	Chl						
22	1.89	Ca-Mg-Mixed	bp	682	21	6	7	676	675
23	2.31	Ca-Mg-Mixed	Chm	689	103	53	58	636	631
24	1.51	Ca-Mg-Mixed	Chm, bp	688	302	35	42	653	645
25	1.33	Ca-Mg-Mixed	Chm, bp	646	41	15	26	631	620
26	0.74	Ca-Mg-Mixed	OCc	848	41	27	35	820	820
27	3.18	Na-HCO3	bp	883	44	35	43	848	840
28	2.39	Na-HCO3	bp, Chm	850	56	22	28	828	822
29	1.18	Na-HCO3	bp	849	162	29	35	820	814
30	1.77	Na-HCO3	bp	934	60	45	45	889	889
31	2.07	Na-HCO3	bp	891	305	23	26	868	864
32	5.55	Na-HCO3	bp	892	51	29	30	864	862
33	5.08	Na-HCO3	bp	707	70	34	37	673	669
34	2.02	Na-HCO3	bp	702	23	18	21	683	681
35	3.56	Na-HCO3	bp						

Would like to  
be P.O. 5.7  
show Form  
not

AR3000098

## Footnotes for Master Hydrogeologic-Hydrochemical Data Table

1. Water samples collected May 5 to May 11, 1988 for chemical analyses by Stephen G. Schmelling, U.S. E.P.A. Robert S. Kerr Laboratory. In general, 3 casing volumes of water were purged before a sample was collected. Samples for metal analysis were filtered and fixed in the field. Alkalinity was titrated at the motel after sampling. Samples were then shipped express to Robert S. Kerr Laboratory. Chemical analyses by U.S. E.P.A. Robert S. Kerr Laboratory. HCO<sub>3</sub> analyses made in the laboratory.
2. pH (EPA) measurements were made by Steve Schmelling with pH paper.  
pH (Weston) were made by Weston/IT personnel with a pH meter during well purging before samples were collected.
3. TCE measurements were made by Weston/IT personnel and reported in final report of Regional Hydrogeologic Investigation, <sup>Hereford Township</sup> ~~Town of Hereford~~ Site, Berks County, Pennsylvania.
4. Data for well elevation, well depth, depth to water (DTW) and water table elevation (WT) is from final report of Regional Hydrogeologic Investigation, <sup>Hereford Township</sup> ~~Town of Hereford~~ Site, Berks County, Pennsylvania.
5. Surface geology at well location is based on comparison of geologic map from Buckwater (1959) and well location map in final report of Regional Hydrogeologic Investigation, <sup>Hereford Township</sup> ~~Town of Hereford~~ Site, Berks County, Pennsylvania. COc- Undifferentiated carbonate rocks, primarily "Tomstown" limestone (The term Tomstown limestone is used in this report. Weston/It uses the term Leithsville Formation. It

is assumed that Leithsville and Tomstown are synonymous.); Chl-Hardyston Formation, basal conglomerate; Chm-Middle Hardyston Formation, primarily quartzite and quartzite sandstone; and, bp-Precambrian Byram Gneiss.

6. Chemical Group based on grouping of water chemistry from Schoeller diagrams.

7. Master Data Table does not include duplicate analyses. These analyses are in Table 2.

## Data quality

All geochemical data have been reviewed and appear to be of high quality. Several samples had duplicate analyses and there is good agreement between duplicates (Table 2). Comparison of total anions to total cations shows a good correlation (fig. 2).

Some data were considered suspect. The percent difference (anions-cations/ anions+cations) for some of the data exceeded the generally accepted limit of  $\pm 5\%$ . (Percent difference provides an internal check of the data.) Those data with percent difference values greater than 5 percent, however, are for dilute waters (TDS less than 75 mg/l or less than 2 meq/l) (fig. 3). Small laboratory measurement error at low concentrations would result in small absolute errors but larger relative (%) type errors. Based on conversation with Dr. Steve Schmelling, EPA Robert S. Kerr Laboratory, the data appear correct. Dr. Schmelling checked with the EPA lab that ran the analyses and was assured there were no measurement errors.

Both EPA and Weston measured pH in the field. There is a general correlation between data sets; they are compared to laboratory measured  $\text{HCO}_3$  (figs. 4 and 5). Dr. Schmelling measured pH of the sample with litmus-type paper; Weston measured pH during well purging with a pH electrode. Identical pH values for different  $\text{HCO}_3$  concentrations suggest pH measurement errors in the EPA data (fig. 4). The measurements made with the electrode should provide more accurate values. Outliers within this data set, however, also suggest problems (fig. 5). There appears to be poor quality data in both sets. These data have been used judiciously.

Well construction is not considered to affect the chemical composition of the ground waters. There is a concern, however, that the use of cement and bentonite may affect water chemistry of recently constructed monitoring wells used at the site. In a following section titled "Schoeller Diagrams", the chemical composition of the ground waters from the Hereford area is divided into three different water types, Na-HCO<sub>3</sub>, Ca-Mg-Mixed, and Ca-Mg-HCO<sub>3</sub>. The difference between the Na-HCO<sub>3</sub> and Ca-Mg-Mixed waters results from increased Na-HCO<sub>3</sub> concentrations in the Na-HCO<sub>3</sub> water. These Na-HCO<sub>3</sub> waters are all located on Blackhead Hill in recently constructed monitoring wells. Monitoring wells in bedrock were open hole in the production zone and cemented above with portland cement and bentonite. Monitoring wells in saprolite and shaley overburden were screened, sand packed, and have a bentonite pellet seal on top of the filter pack. There is a concern that this cement and bentonite may be the cause of the increase Na and HCO<sub>3</sub>. However, several other monitoring wells were also constructed in locations other than on Blackhead Hill. These wells produce ground waters with other water chemistry types, and do not appear to be affected by well construction. Well construction does not appear to affect water chemistry but the reader should be aware of the potential problem.

EPA Hersford Data Duplicate Analyses

EPA duplicate analyses collected by S. Schmelling											Table compiled 8-21-88	
SADNO	LOCATION	NO3(N)	mg/l NH3	(N) mg/l	SO4 (mg/l)	Cl (mg/l)	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Fe (mg/l)	SiO2 (mg/l)
7845	MW1.10B	4	0	0	14	8	9.8	4.2	12	4.4	0	7.65
7845a	MW1.10B	3.7	0	0	11.8	7.2	10.4	4.52	12.4	4.6	0	
7829	MW1R	2.2	0	0	4.3	3.5	5.8	2.9	7.7	1.4	0	7.15
7829a	MW1R	2.1	0	0	3.7	1.3	6.59	3.44	7.89	1.53	0	
7856	MW1R	2.2	0	0	5.1	2	5.9	3	8	1.4	0	7.39
7837	MW2R	3.9	0	0	36	7.5	4.1	0.9	26	11	0	6.29
7837a	MW2R	3.7	0	0	34.6	5.1	4.17	1.15	26.5	11.5	0	
7838	MW2R	3.9	0.28	0	36	8	3.9	0.9	26	11	0	6.22
7841	MW3DOB	0.3	0	0	13	3	11	4.2	3.9	1.3	0.2	3.80
7858	MW3DOB	0.1	0.35	0	11	4	8.8	2.4	4.3	1.1	0.4	3.81
7862	MW4R	0.7	0	0	4	2	1.9	0.9	13	7.4	0	4.00
7862a	MW4R	0.65	0	0	4.4	2.5	2.03	1.12	13.5	7.67	0	
7824	MW5DOB	5.3	0	0	4.3	4	5.8	3.7	4.2	1.6	0	2.87
7824a	MW5DOB	5.4	0	0	3.9	3.3	5.89	3.9	4.27	1.7	0	
7864	MW6R	2.2	0	0	14	18	6.7	1.7	21	11	0	2.66
7864a	MW6R	2.2	0	0	11.1	17.9	6.81	1.97	22	11.9	0	
7826	MW8R	0.9	0.1	0	9.1	5	2.8	2.6	18	13	0	1.20
7826a	MW8R	0.9	0.06	0	9	3	2.95	2.85	18.3	13.1	0	
7855	MW8R	0.9	0.35	0	12	4	2.8	2.5	18	13	0	1.25
7827	MW10B	0.9	0.06	0	0	6.2	3	4.8	1.8	3.6	1.3	0
7828	MW10B	0.8	0.06	0	0	6.2	3	4.9	1.8	3.3	1.1	0
7840	Karalosky	0.85	0.06	0	0	7.5	3	1.89	1.3	25	15	0
7840a	Karalosky	0.65	0.05	0	0	6	2.5	2.1	1.49	25.8	15.1	0
7832	K. Metzler	1.4	0	0	3.7	3.5	2.6	0.9	2	0.7	0	3.70
7832a	K. Metzler	1.2	0	0	3.1	1.5	2.77	1.14	2.06	0.79	0	
7835	L. Miller	2.3	0.16	0	0	21	8	3.9	0.7	22	8.4	0
7835a	L. Miller	2.2	0.16	0	0	20	5.1	4.47	0.92	22.6	8.86	0

AR300103

EPA Hereford Data Duplicate Analyses

Alk (mg/l)	HCO3 (mg/l)	TDS (mg/l)	SO4 (mg/l)	Cl (mg/l)	HCO3 (mg/l)	NO3 (mg/l)	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)
46	54.08	118.13	0.29	0.23	0.89	0.29	0.43	0.11	0.60	0.36
46	56.08	110.7	0.25	0.20	0.92	0.26	0.45	0.12	0.62	0.38
30	36.57	71.52	0.09	0.10	0.60	0.16	0.25	0.07	0.38	0.12
30	36.57	63.12	0.08	0.04	0.60	0.15	0.29	0.09	0.39	0.13
34	41.45	76.44	0.11	0.06	0.68	0.16	0.26	0.08	0.40	0.12
72	87.78	183.47	0.75	0.21	1.44	0.28	0.18	0.02	1.30	0.90
72	87.78	174.7	0.72	0.14	1.44	0.26	0.18	0.03	1.32	0.95
64	78.03	174.23	0.75	0.23	1.28	0.17	0.10	0.04	2.14	0.90
38	46.33	87.03	0.27	0.08	0.76	0.02	0.48	0.11	0.19	0.11
36	43.89	80.15	0.23	0.11	0.72	0.01	0.38	0.06	0.21	0.09
66	80.46	114.36	0.08	0.06	1.32	0.05	0.08	0.02	0.65	0.61
66	80.46	112.33	0.09	0.07	1.32	0.05	0.09	0.03	0.67	0.63
12	14.63	46.4	0.09	0.11	0.24	0.38	0.25	0.09	0.21	0.13
12	14.63	42.99	0.08	0.09	0.24	0.39	0.26	0.10	0.21	0.14
76	92.66	169.92	0.29	0.51	1.52	0.16	0.29	0.04	1.05	0.90
76	92.66	166.54	0.23	0.50	1.52	0.16	0.30	0.05	1.10	0.98
82	99.97	152.67	0.19	0.14	1.64	0.06	0.12	0.07	0.90	1.07
82	99.97	150.13	0.19	0.08	1.64	0.06	0.13	0.07	0.91	1.08
92	112.16	166.96	0.25	0.11	1.84	0.06	0.12	0.06	0.90	1.07
4.92	18	21.94	48.46		0.13	0.08	0.36	0.21	0.05	0.18
5.11	18	21.94	48.15		0.13	0.08	0.36	0.21	0.05	0.16
4.27	112	136.55	195.36		0.16	0.08	2.24	0.08	0.03	1.25
	112	136.55	190.19		0.12	0.07	2.24	0.09	0.04	1.29
8	9.75	28.25	0.08	0.10	0.16	0.10	0.11	0.02	0.10	0.06
8	9.75	22.31	0.06	0.04	0.16	0.09	0.12	0.03	0.10	0.06
8.05	72	87.78	162.13		0.44	0.23	1.44	0.17	0.02	1.10
	72	87.78	151.93		0.42	0.14	1.44	0.19	0.02	1.13

AR300104

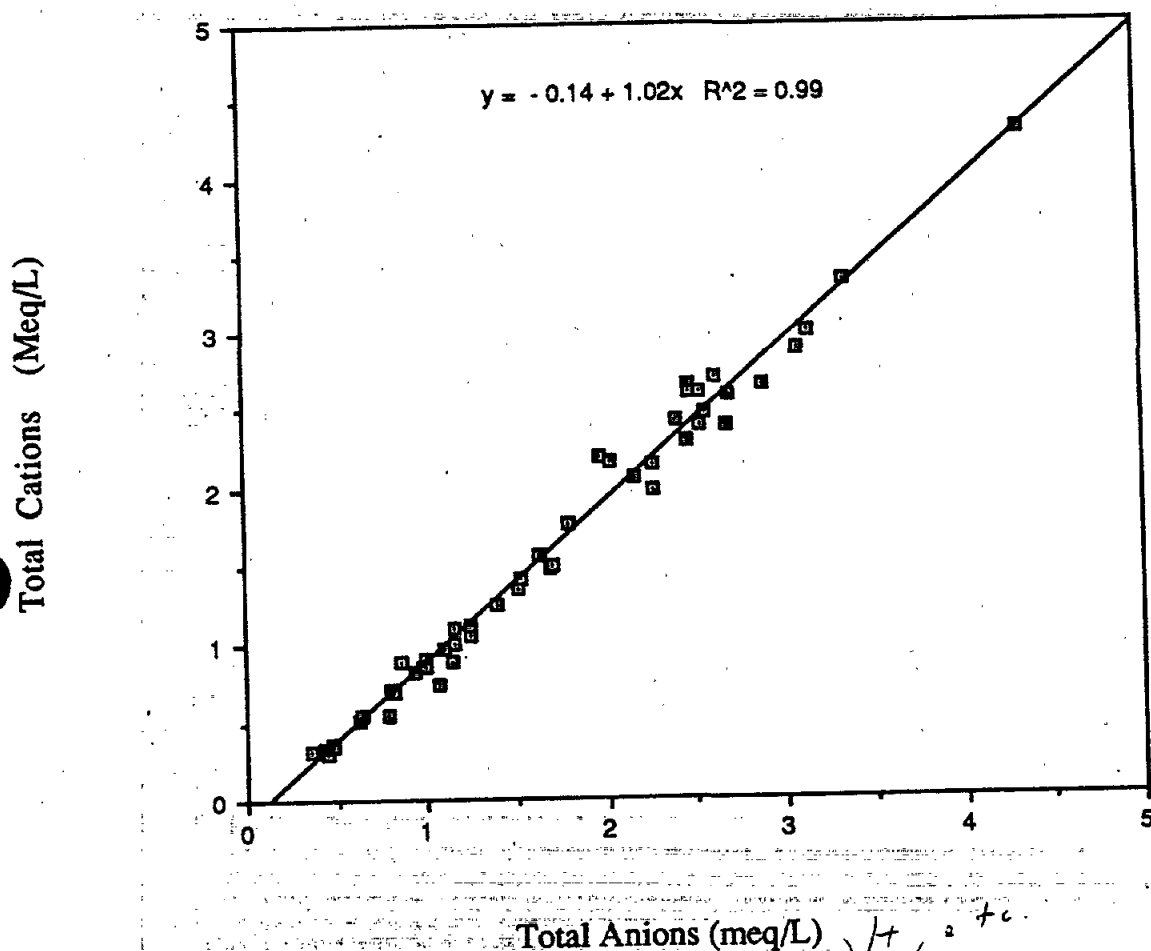
EPA Hereford Data Duplicate Analyses

Antons (meq/l)	Cations (meq/l)	An-Cat	An-Cat	Percent dif	TDS (mg/l)
1.69	1.49	0.19	3.18	0.12	118.13
1.63	1.57	0.07	3.20	0.04	110.70
0.94	0.83	0.12	1.77	0.13	71.52
0.88	0.89	-0.03	1.76	-0.04	63.12
1.00	0.85	0.15	1.85	0.15	76.44
2.68	2.40	0.27	5.08	0.10	183.47
2.57	2.48	0.09	5.05	0.04	174.70
2.42	3.19	-0.77		-0.32	174.23
1.14	0.89	0.25	2.02	0.22	87.03
1.07	0.75	0.32	1.82	0.30	80.15
1.51	1.36	0.15	2.87	0.10	114.36
1.53	1.42	0.11	2.95	0.07	112.33
0.82	0.69	0.13	1.51	0.16	46.40
0.80	0.71	0.09	1.51	0.11	42.99
2.47	2.29	0.19	4.76	0.08	169.92
2.41	2.42	-0.01	4.84	0.00	166.54
2.03	2.16	-0.12	4.19	-0.05	152.67
1.97	2.19	-0.22	4.17	-0.11	150.13
2.27	2.15	0.11	4.42	0.05	166.96
0.11	0.64	0.54	0.10	1.18	0.15
0.09	0.63	0.51	0.12	1.14	0.18
1.23	2.54	2.60	-0.06	5.14	-0.02
1.24	2.48	2.66	-0.18	5.14	-0.07
0.44	0.29	0.14	0.73	0.33	28.25
0.35	0.32	0.03	0.67	0.10	22.31
0.69	2.27	1.98	0.29	4.24	0.13
0.73	2.16	2.07	0.08	4.23	0.04

AR300105

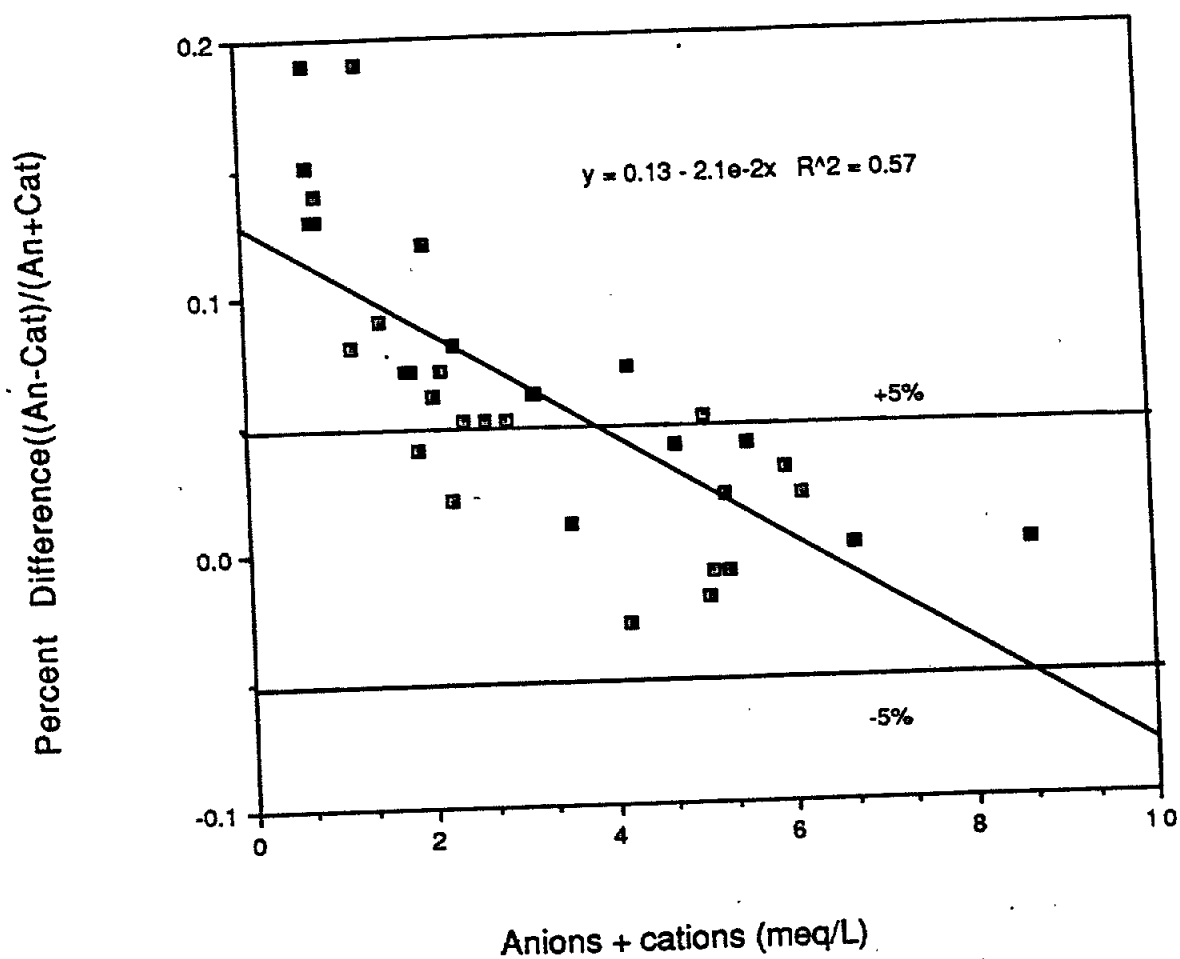


Figure 2. Total Cations Versus Total Anions  
for Total EPA Hereford data



What is  
significance vis a vis H<sub>2</sub>O  
how about brief section on theory  
of Form. H<sub>2</sub>O chem & geo by dialog

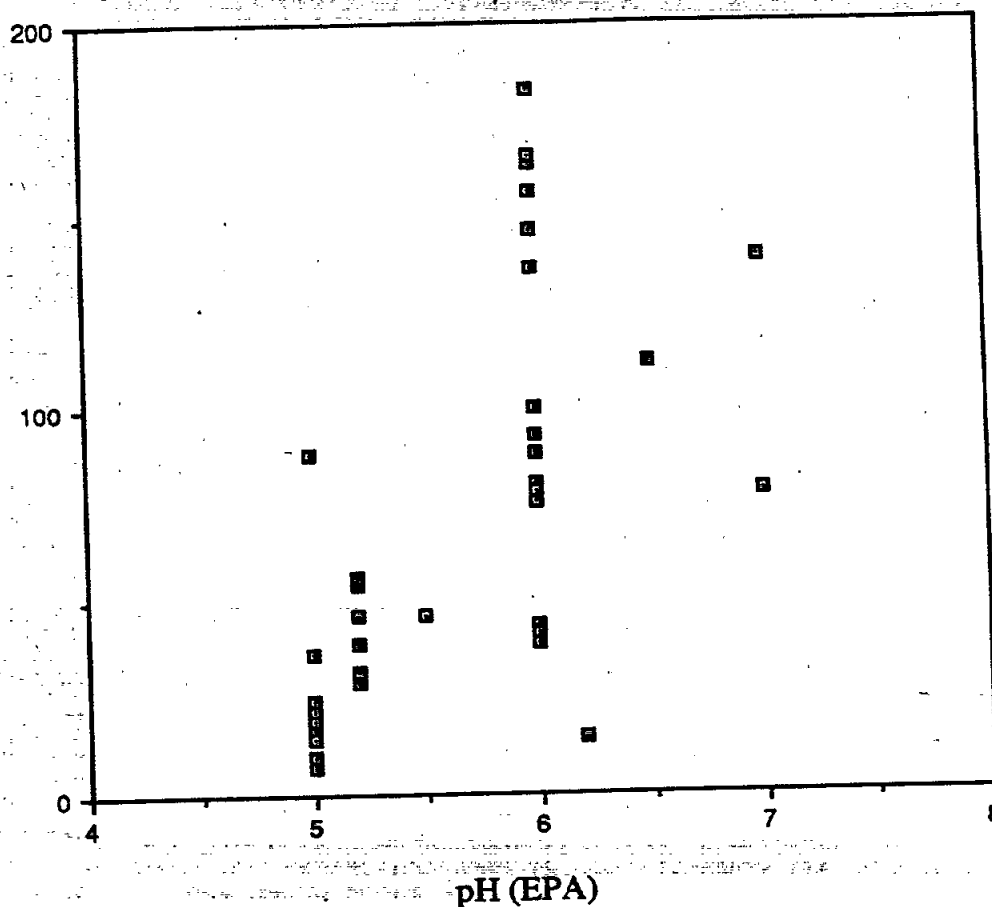
Figure 3. Percent Difference  
versus Anions +Cations



AR300107

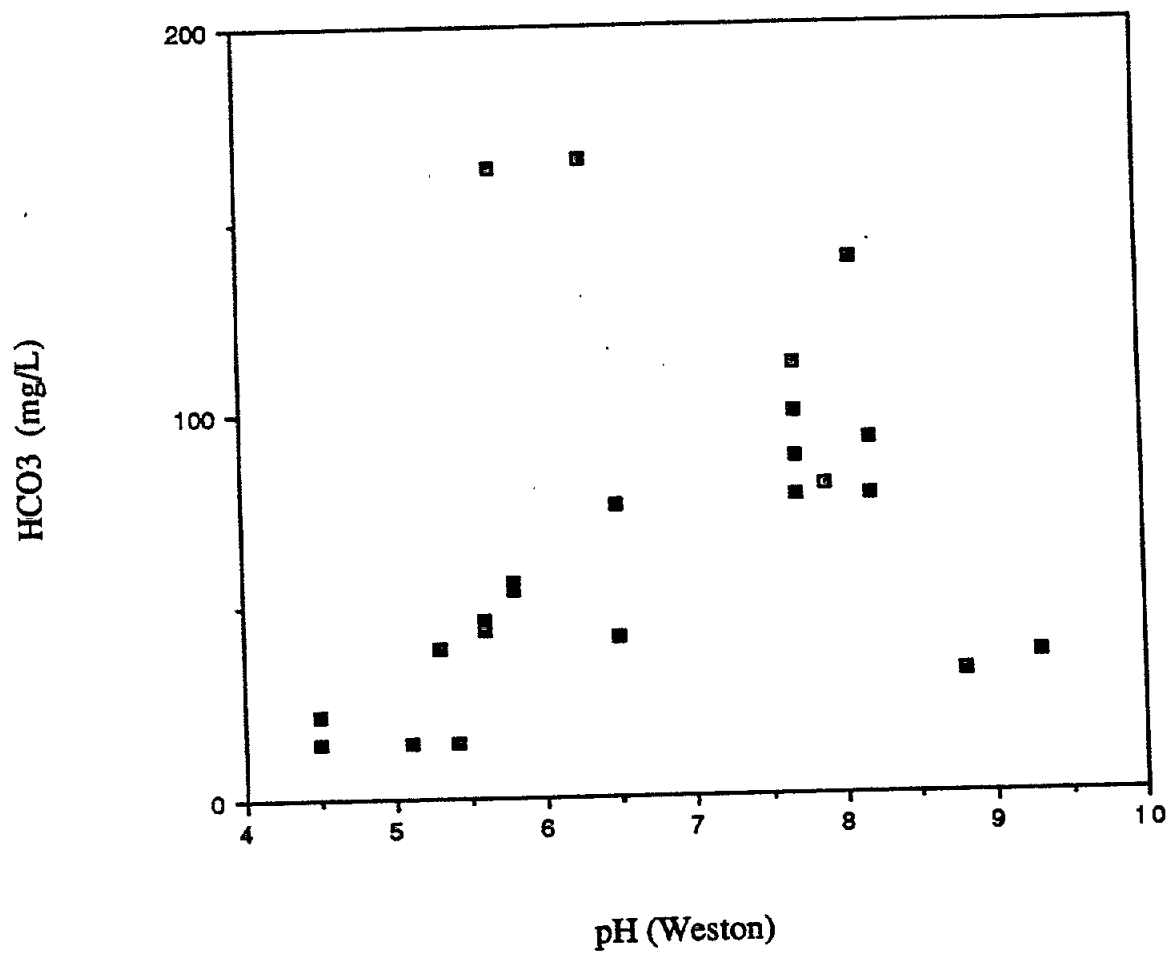
HCO<sub>3</sub> (mg/L)

Figure 4. pH (EPA) versus HCO<sub>3</sub>  
for Total EPA Hereford Data



AR300108

Figure 5.  $\text{HCO}_3$  versus pH  
(as measured by Weston/ REAC)



## Schoeller Diagrams

All data have been analyzed in the context of Schoeller plots. Schoeller plots graph the chemical composition of each of the major ionic species. In this way a visual chemical signature can often be determined based on chemical composition and concentration. For Schoeller plots, concentrations typically are expressed as the log of the equivalent parts per million for each ionic species. Data for this study, however, has been plotted as arithmetic concentrations rather than logarithmic because of the generally low concentrations of all the waters. Log plots tend to subdue differences in the chemical composition. Arithmetic plots are therefore used to enhance these differences.

Monitoring and domestic water wells were located on the geologic map of the Boyertown Quadrangle (Buckwalter, 1959) to determine whether there were distinct chemical compositions from wells producing from different formations. If there were distinct water chemistries, then more could be learned about the ground-water flow systems. Two or three general chemical compositions were observed with this approach. They were waters from 1) the Tomstown limestone (referred to as the Leithsville Formation in Weston/IT, 1988), 2) Precambrian gneisses and sapprolitic overburden from the gneisses and 3) quartzite in the Hardyston quartzite (sandstone) Formation. Water chemistry was not 100% distinct for specific geologic map units and probably results because some of the wells may produce from a deeper formation than

the formation that has been mapped at land surface. Similarly, some of the geologic contacts between formations are approximate. Wells located near mapped contacts could be with in one formation or the other. Because of these outliers in the data, chemical compositions of the waters were regrouped so as to represent one distinct water type rather than one specific mapped geologic formation.

The 3 groups are 1) Ca-Mg-Mixed (fig. 6), 2) Na-HCO<sub>3</sub> (fig. 7) and 3) Ca-Mg-HCO<sub>3</sub> (fig. 8). One well is shown on Figure 10 which appears as a Ca-Mg-HCO<sub>3</sub> that has had Na-Cl added (i.e. possible surface pollution).

1) Ca-Mg-Mixed waters (fig. 6): These are low total dissolved waters that come predominantly from bedrock wells located in either Precambrian gneiss or the Hardyston Formation. Both of these units (based on the mineralogic description in Buckwalter (1959)) are quartz-rich/carbonate-poor rocks. Ca and Mg appear as the dominant cations and there is no dominant anion.

2) Na-HCO<sub>3</sub> waters (fig. 7): These are low total dissolved solid waters that are from the monitoring wells on Blackhead Hill. They show an evolution of increasing Na and HCO<sub>3</sub>. These wells are located in the Hardyston Formation or gneissic sapprolite. The increase in Na and HCO<sub>3</sub> may represent dissolution of feldspars or exchange reactions with clays. These waters appear distinct from the Ca-Mg-HCO<sub>3</sub> waters, which is

interesting since one would suspect some mixing between waters of the two different rock types.

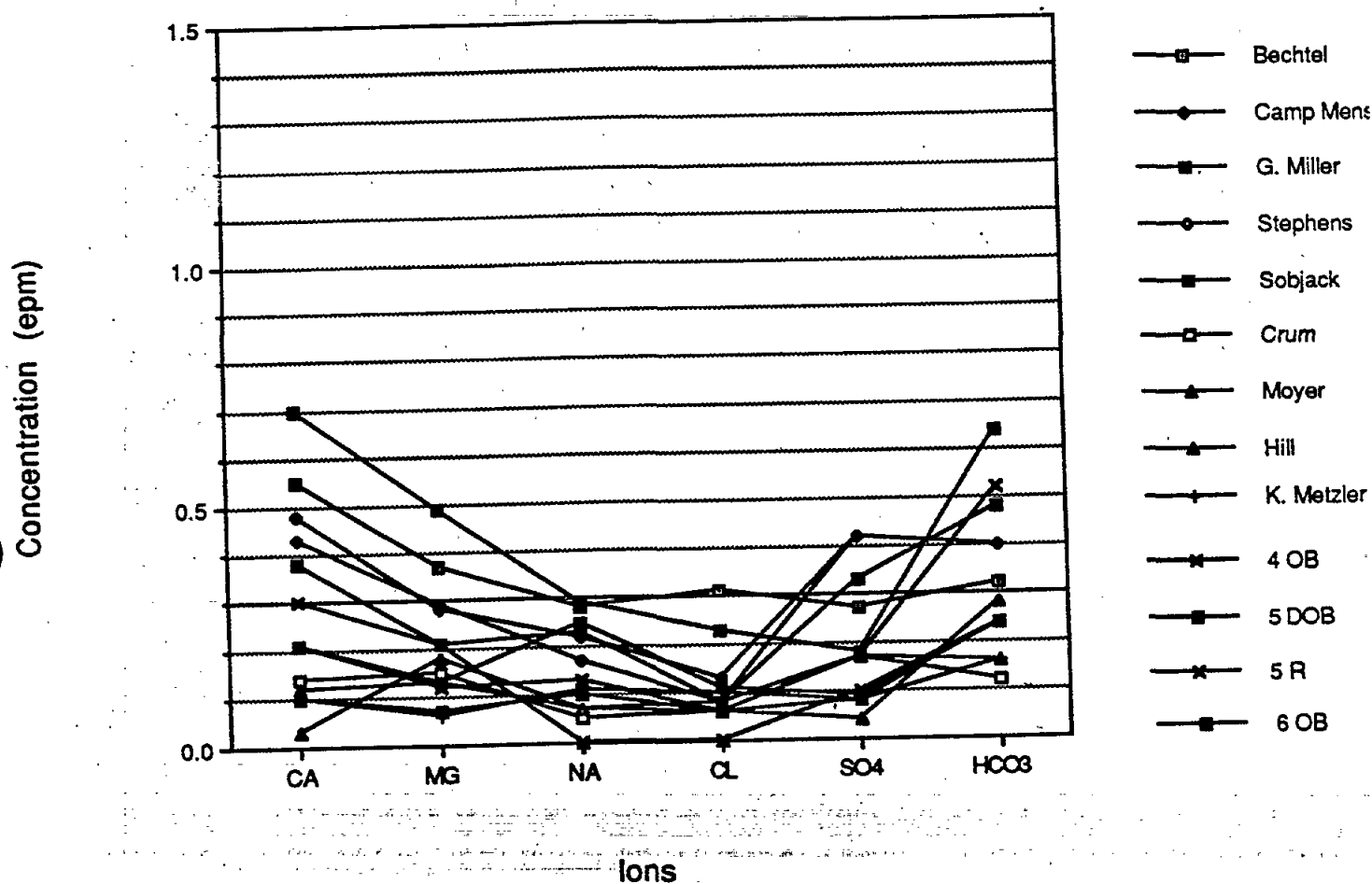
- 3) Ca-Mg-HCO<sub>3</sub> waters (fig. 8): Ca-Mg-HCO<sub>3</sub> water is significantly different from either of the previously two described waters both in concentration and chemical composition. These waters have a higher total dissolved solids and are dominated by Ca and Mg for the cations and HCO<sub>3</sub> for the anions. This chemical composition is to be expected for a ground water in equilibrium with limestone and/ or dolomite. The concentration scale has been changed in figure 9 , so that it will be the same for Figures 6 and 7. It shows that the Na-HCO<sub>3</sub> and Ca-Mg-HCO<sub>3</sub> waters are significantly different from the Ca-Mg-HCO<sub>3</sub> water. Within the Ca-Mg-HCO<sub>3</sub> group there may be two subgroups, a high HCO<sub>3</sub> and a lower HCO<sub>3</sub> water.
- 4) Ca-Mg-Na-Cl-HCO<sub>3</sub> water (fig. 10): There is one water with a Ca-Mg-HCO<sub>3</sub> composition plus similar concentrations of Na and Cl. The water may represent a mixing of a Na-Cl source with the Ca-Mg-HCO<sub>3</sub> water. It's Ca-Mg-HCO<sub>3</sub> suggests that the well is screened in the Tomstown limestone, though the drilling log for 70B did not identify any limestone in the hole.

The next stages of investigation are to use other geochemical approaches to evaluate whether these chemical groupings are consistent and whether there is an evolution of water chemistry from one water type to another such that

ground water flow paths can be distinguished, and then to evaluate what controls the water chemistry has on the distribution of TCE.

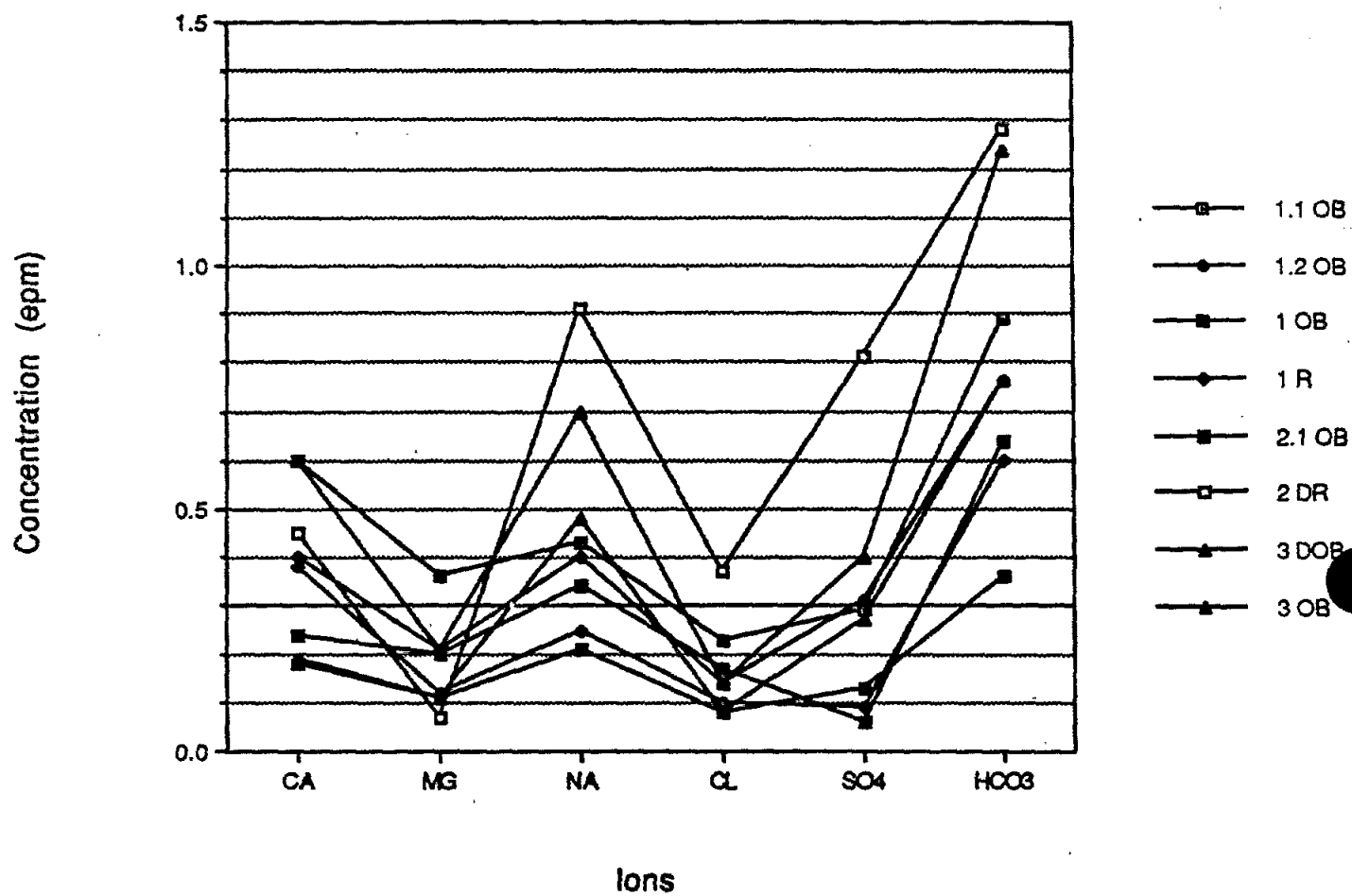


Figure 6. Schoeller data for Ca-Mg-Mixed



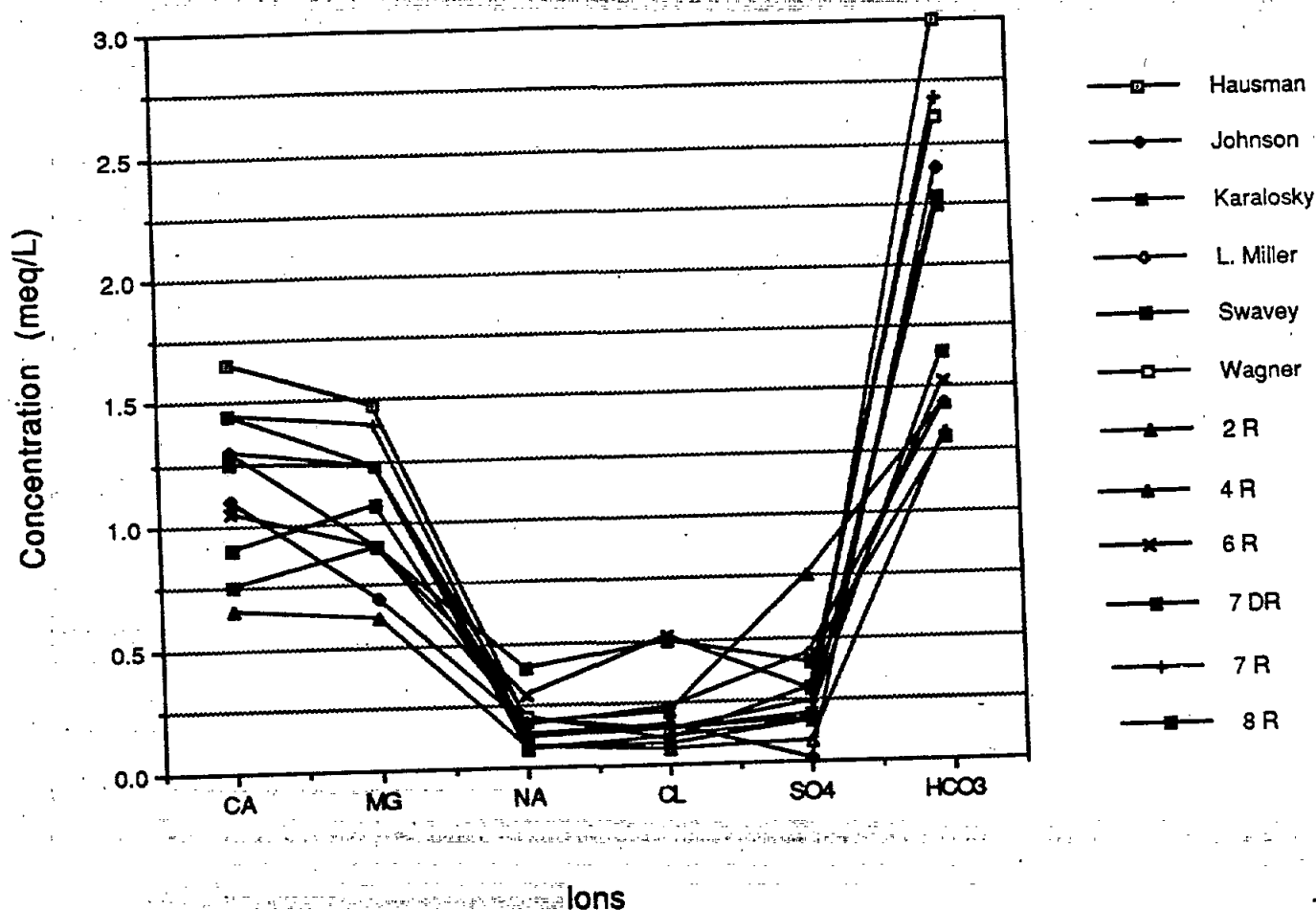
AR300114

Figure 7. Schoeller plot Na-HCO<sub>3</sub> water



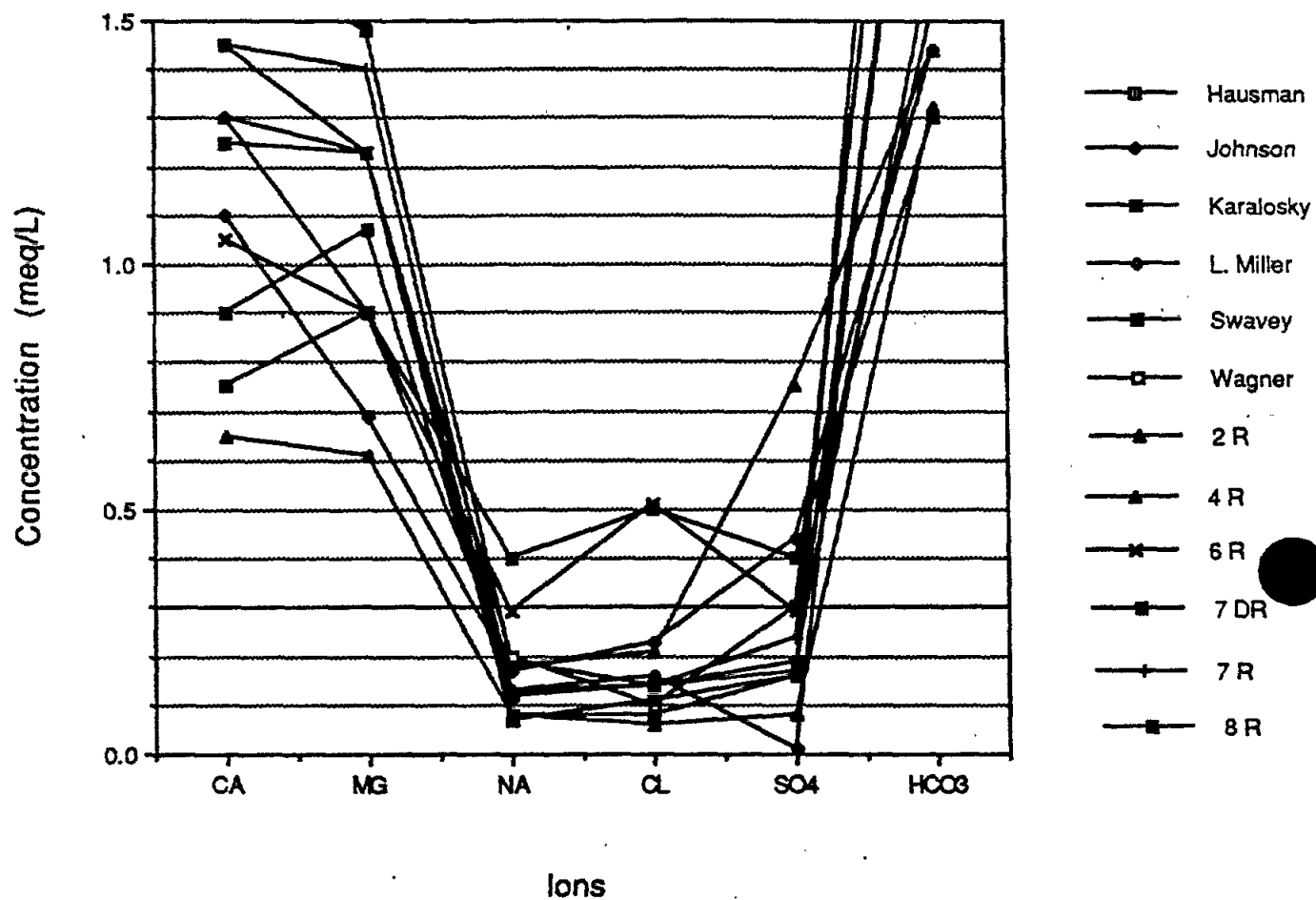
AR300115

Figure 8. Schoeller data for Ca-Mg-HCO<sub>3</sub>



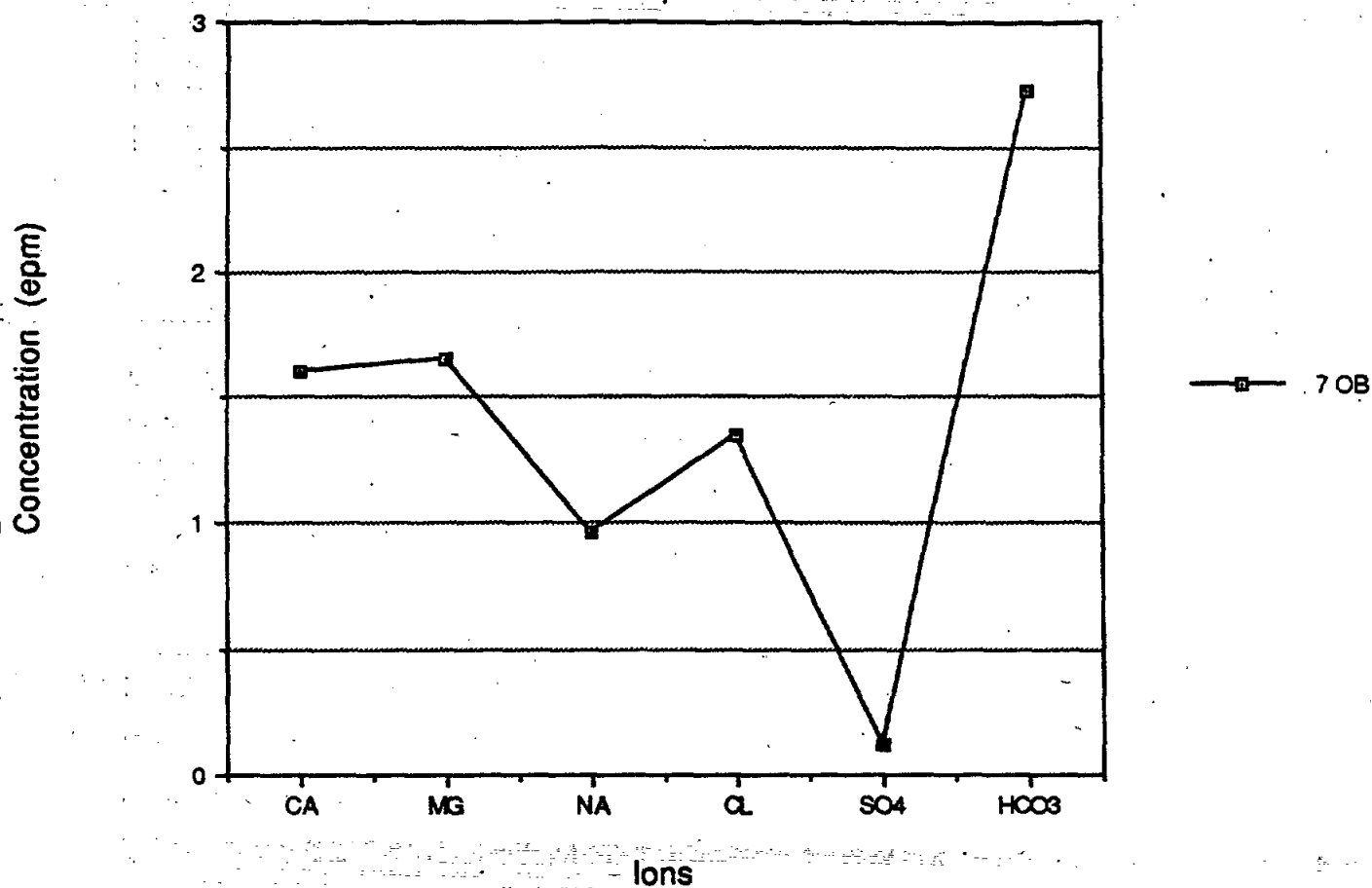
AR300116

Figure 9. Schoeller data for Ca-Mg-HCO<sub>3</sub>



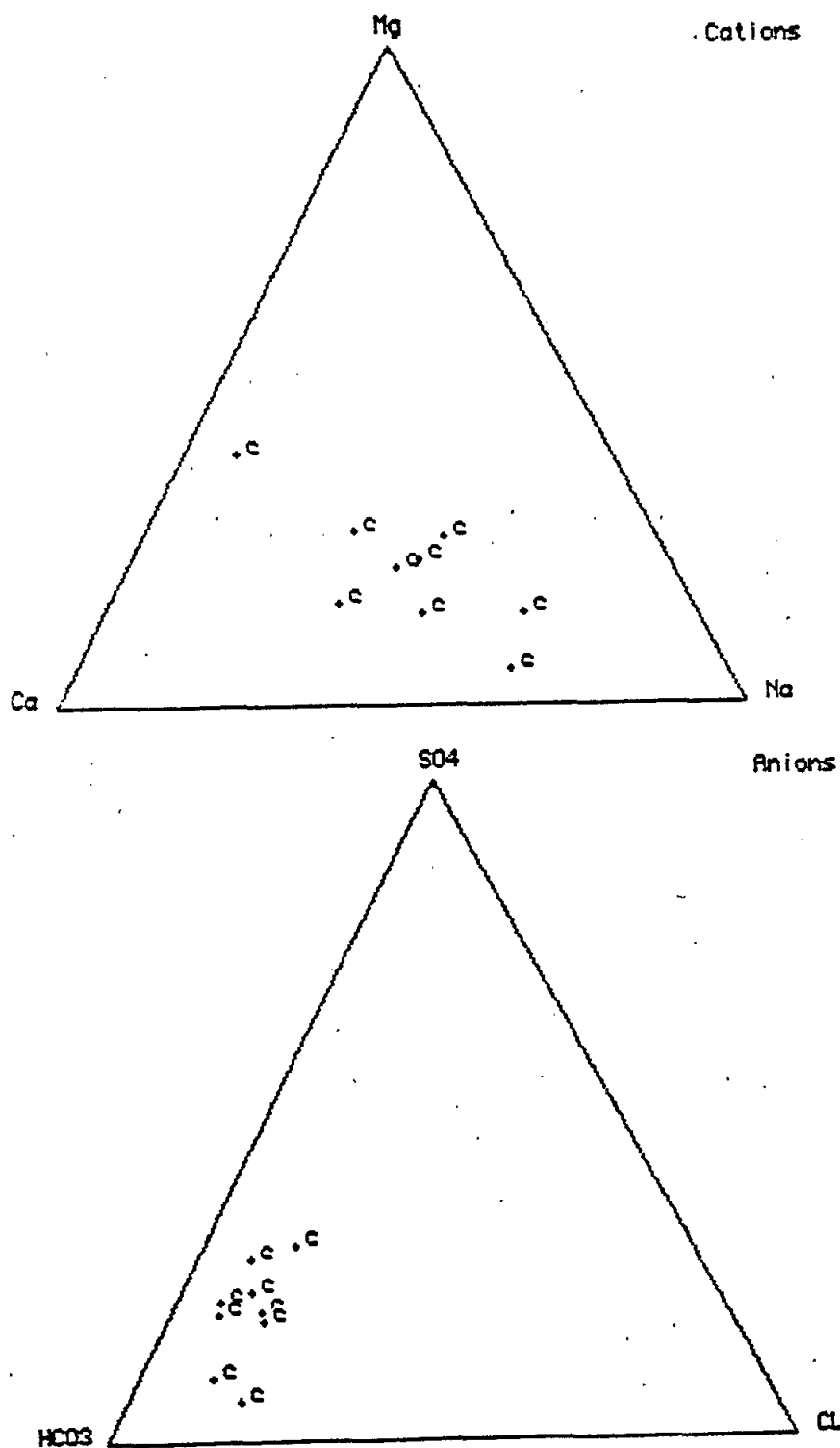
AR300117

Figure 10. Schoeller data  
for Ca-Mg-HCO<sub>3</sub> with NaCl



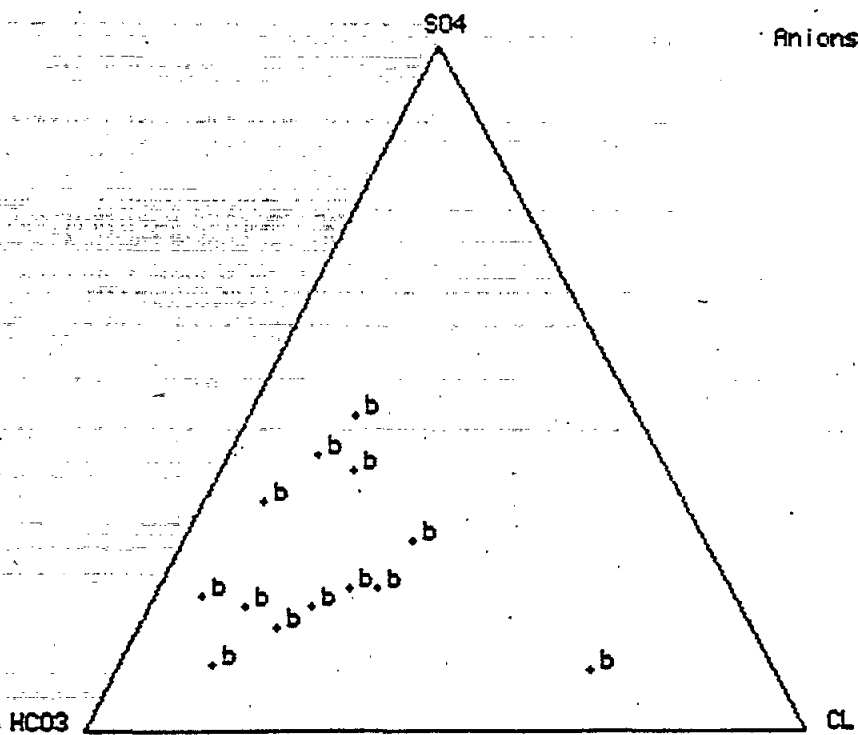
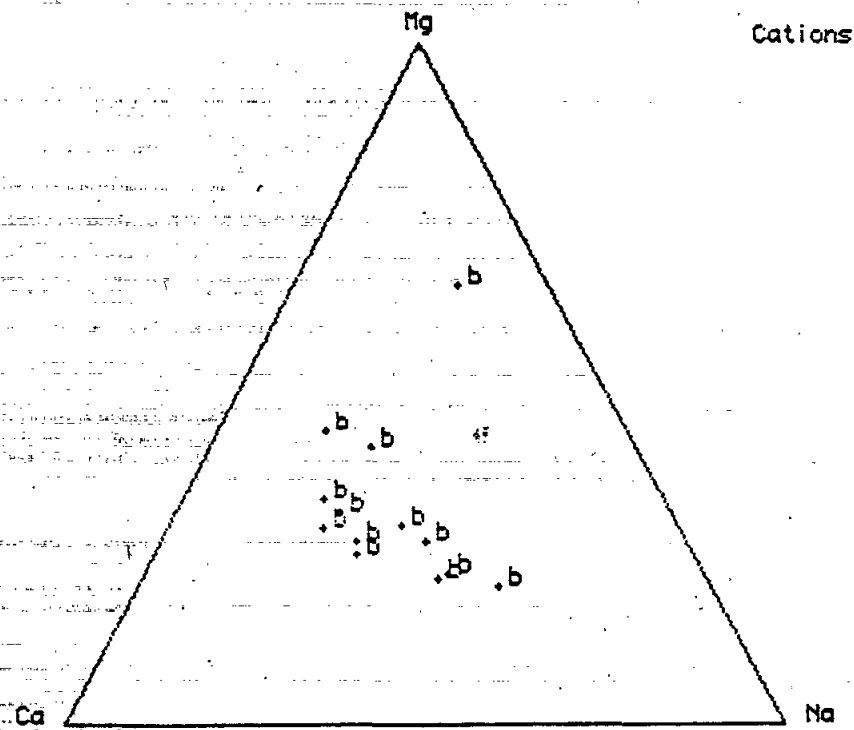
AR300118

Figure 11



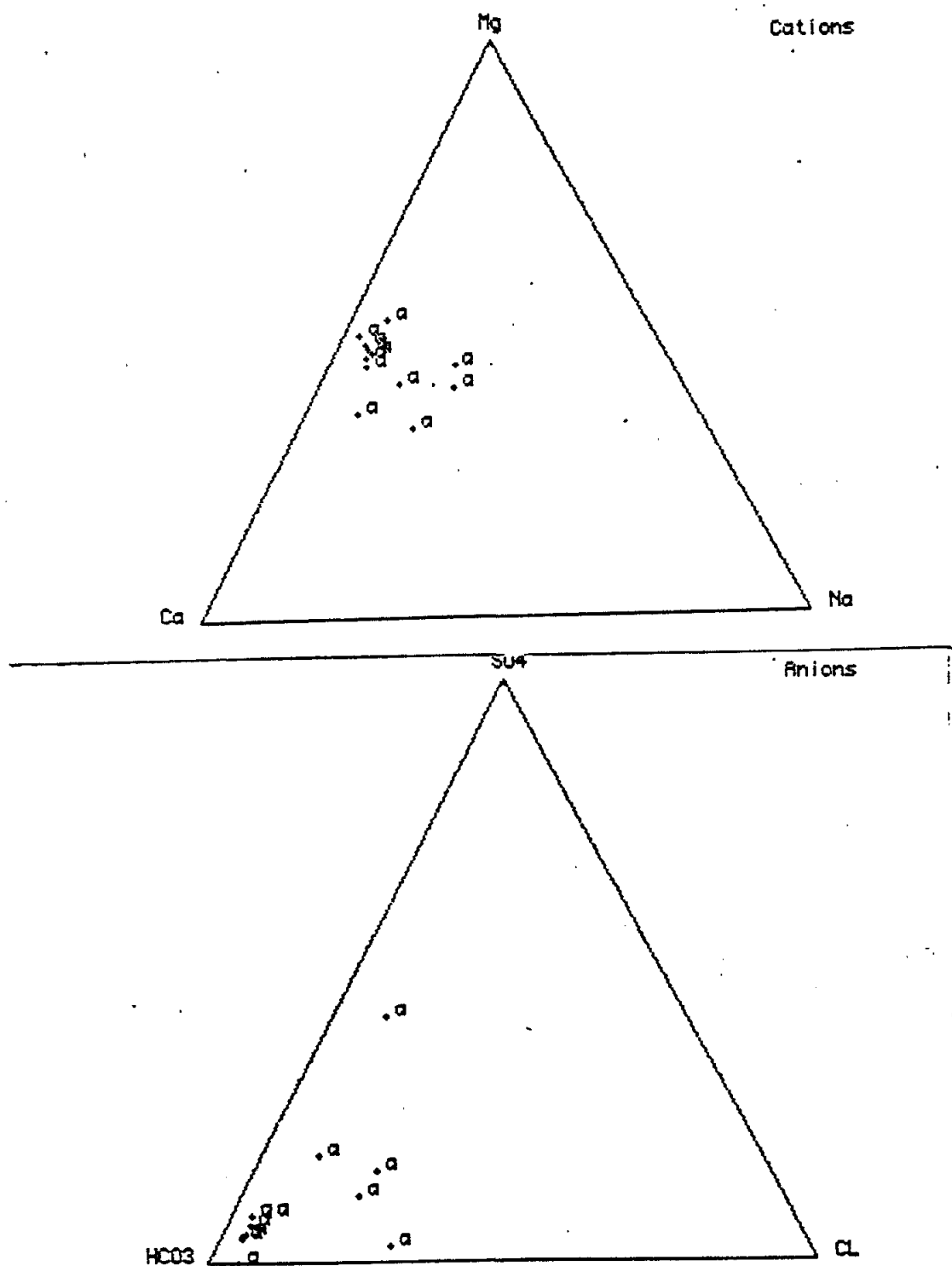
AR300119

Figure 12



AR300120

Figure 13



AR300121



## Piper Diagrams

A Piper diagram( Piper, 1944) is a graphical method for displaying the chemical composition of a water or set of water analyses. Cations and anions are presented as relative percentage of the sum of the milliequivalents (meq/L) of the anions or cations, but does not show variations in concentration. It is a useful technique for displaying the general water chemistry of a water or set of waters. It also can be used for showing mixing trends or the chemical evolution of a water.

The Na-HCO<sub>3</sub>, Ca-Mg-Mixed, and Ca-Mg-HCO<sub>3</sub> waters, as identified on the Schoeller diagrams (figs. 6, 7, and 8), are displayed in figures 11, 12, and 13, respectively. The Ca-Mg-HCO<sub>3</sub> waters (fig. 13) show the tightest pattern of data. The cation triangle for the Na-HCO<sub>3</sub> (fig. 11) shows the change from a Ca-Mg to Na dominance with the chemistry in the anion triangle migrating toward the HCO<sub>3</sub> corner of the triangle. The Ca-Mg-Mixed (fig. 12) show a dispersed pattern with the anion data predominantly between the HCO<sub>3</sub> and SO<sub>4</sub> corners and the cation data dispersed in the center of the triangle. Based on this Piper diagram analysis, this water type might be more correctly referred to as a Mixed-HCO<sub>3</sub>-SO<sub>4</sub> water rather than the original designation of a Ca-Mg-Mixed type of water which was based on compositional trends of the Schoeller diagram for this water type (fig. 7).

The Piper diagram analysis agrees with the earlier delineation of three water types based on the Schoeller diagram analysis. Additional analysis by evaluating chemical trends by a series of

scatter plots will shows these three groupings to be consistent. These analyses are discussed in the following sections.

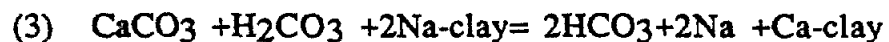
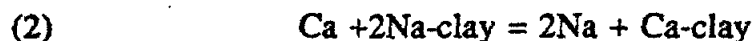
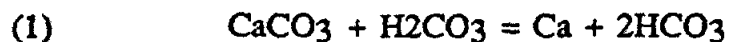
## Chemical controls on Na-HCO<sub>3</sub> waters

The Schoeller diagram (fig. 6) identified a set of waters as Na-HCO<sub>3</sub> waters and represent waters from monitoring wells in overburden material and a couple bedrock wells on Blackhead Hill. Total Dissolved Solids (TDS) range from 48 to 220 mg/L; these concentrations are intermediary between the Ca-Mg-Mixed and Ca-Mg-HCO<sub>3</sub>. Scatter diagrams were used to determine whether these waters represented a definable set of waters that are chemically distinct from other water types, determine whether there is internal chemical consistency within the group, and identify mineralogic reactions which may be controlling the water chemistry.

They are labeled as Na-HCO<sub>3</sub> waters because of the increases in both Na and HCO<sub>3</sub> (fig. 14), a trend not observed for the other waters. Other trends were also observed. Additional trends are between HCO<sub>3</sub> vs SO<sub>4</sub> (fig. 15), pH vs SO<sub>4</sub> (fig. 16), Na vs SiO<sub>2</sub> (fig. 17), and pH vs HCO<sub>3</sub> (fig. 18), where HCO<sub>3</sub> and SO<sub>4</sub> increase directly, pH increase with both HCO<sub>3</sub> and SO<sub>4</sub>. There appears an inverse correlation between Na and SiO<sub>2</sub>. There is no correlation between Ca vs SiO<sub>2</sub> (fig. 19) or Mg vs SiO<sub>2</sub> (fig. 20). No correlation was observed between any chemical species and TCE.

Common reactions for Na-HCO<sub>3</sub> water are calcite solution (1) and cation exchange of Na<sup>+</sup> for Ca<sup>++</sup> on clays (2). Na, HCO<sub>3</sub> and pH typically rise (3).

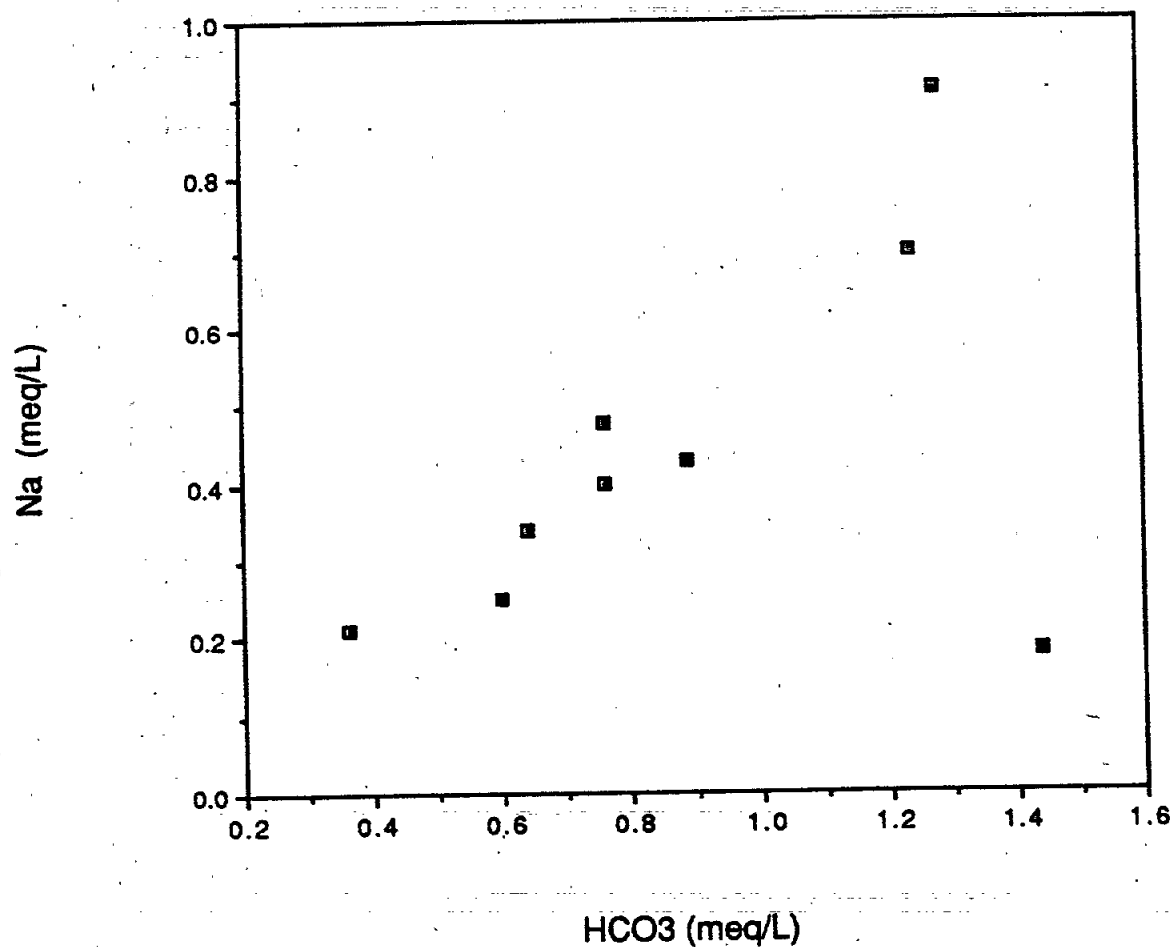
(Eq. 3 = Eq. 1 + Eq. 2). Cation exchange continually reduces the Ca in solution and undersaturates the water with respect to calcite so that more calcite can be dissolved.



The rise in pH suggests a limited acid source. As calcite is dissolved the  $\text{H}^+$  is used in the formation of  $\text{HCO}_3$ , causing the pH to rise to approximately 8-9. The increase in  $\text{SO}_4$ , however, suggests pyrite oxidation, which would indicate an open acid system and pH should not rise. An alternate geochemical reaction for developing Na- $\text{HCO}_3$  waters is by dissolution of sodic feldspars. The inverse correlation between Na and  $\text{SiO}_2$ , however, argues against this reaction. The lack of correlation between Ca vs  $\text{SiO}_2$  and Mg vs  $\text{SiO}_2$  also argues against the dissolution of silicate minerals. Silicate mineral dissolution appears as an important reaction for the Ca-Mg-Mixed water type (see next section).

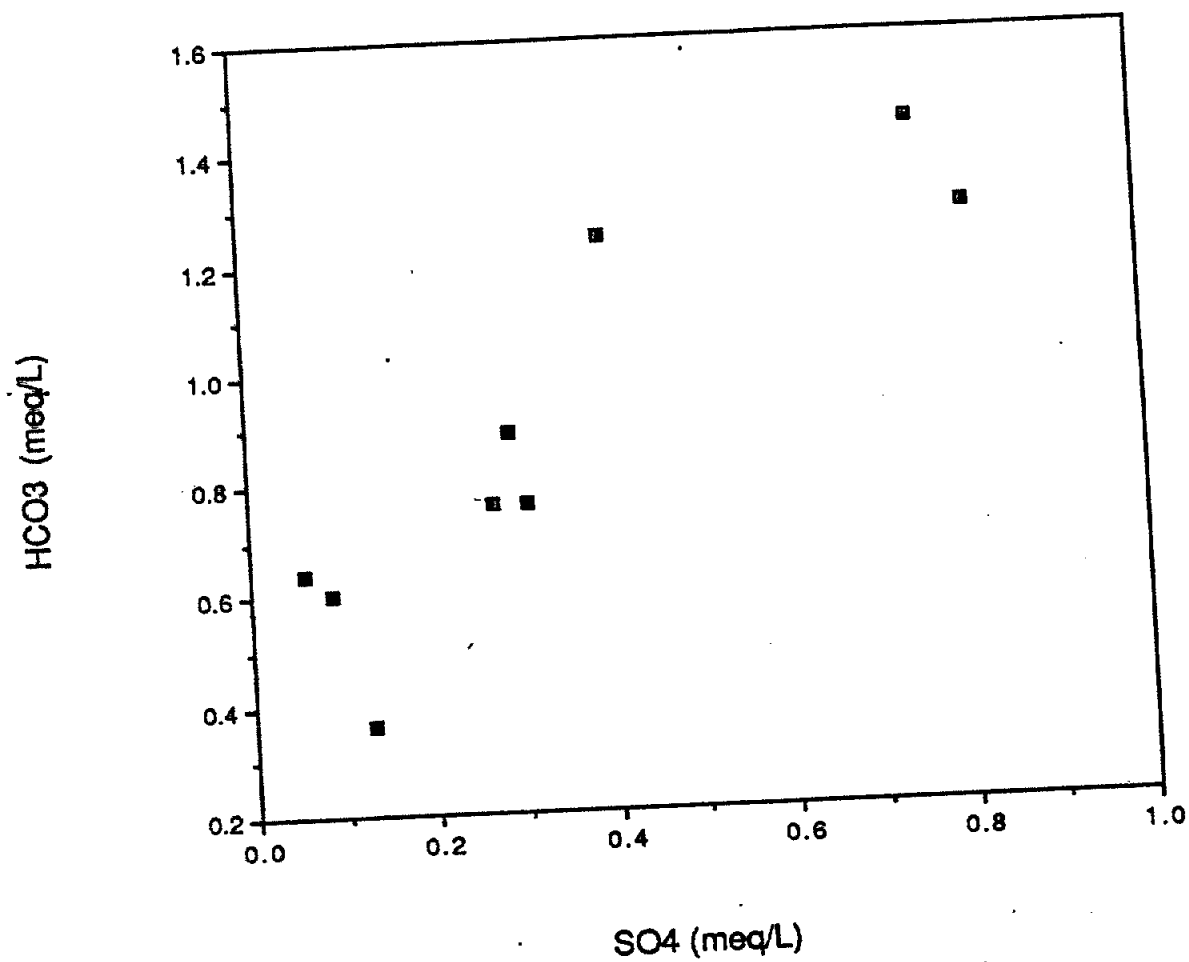
The identification of exact mineralogic reactions cannot be done with the limited data available for this study. It is more important to assign a possible distinct chemical signature to a set of ground waters that come predominantly from the monitoring wells on Blackhead Hill. These waters appear unique from the other two water types and appear to have chemical consistency. These waters appear specific to one geographic area rather than one lithology. The Na- $\text{HCO}_3$  waters come from wells in both Hardyston Formation and in the gneiss sapprolite.

Figure 14. Na vs HCO<sub>3</sub> NaHCO<sub>3</sub>



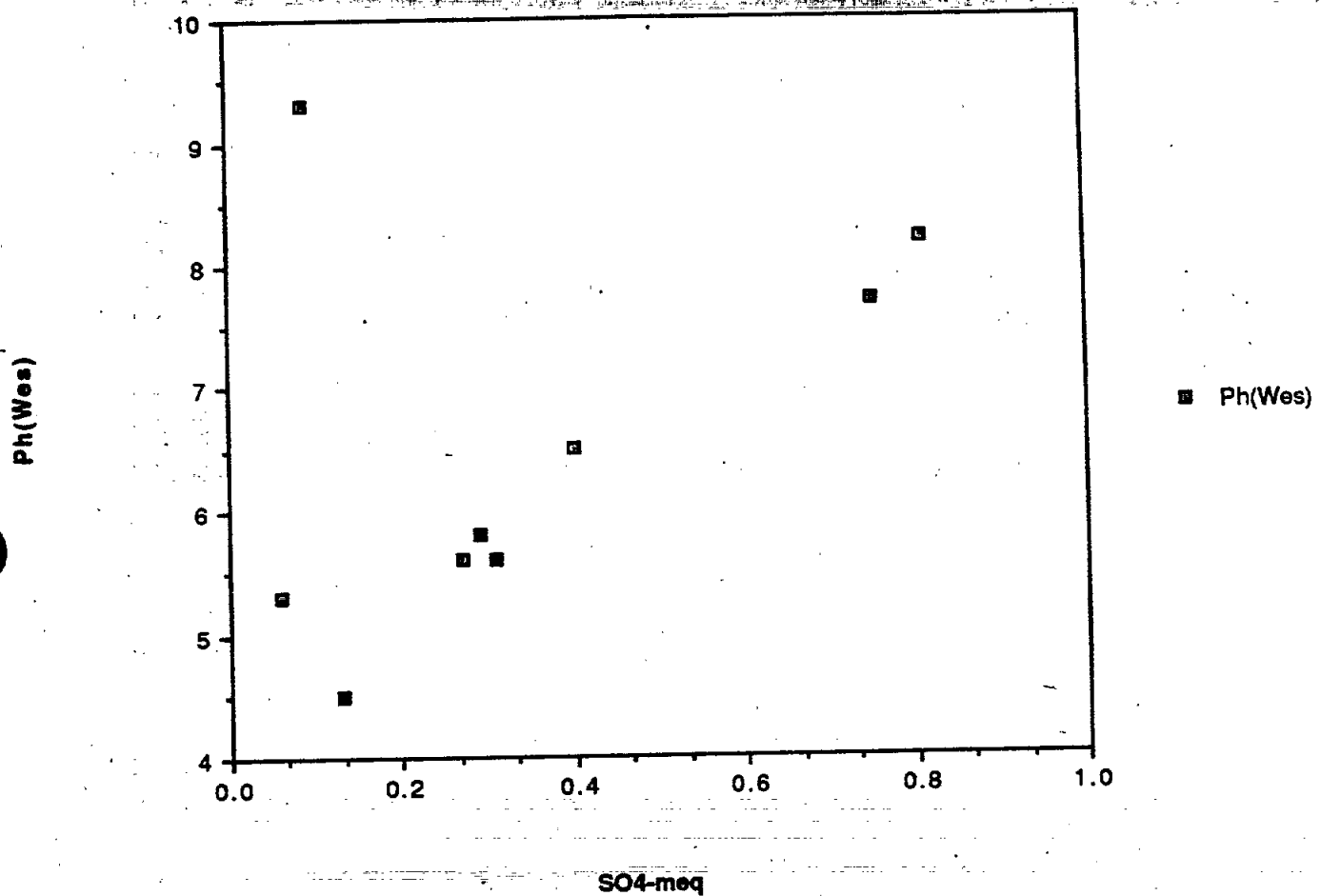
AR300126

Figure 15. HCO<sub>3</sub> vs SO<sub>4</sub> NaHCO<sub>3</sub>



AR300127

Figure 16. pH (WES) vs SO<sub>4</sub> NaHCO<sub>3</sub>



AR300128

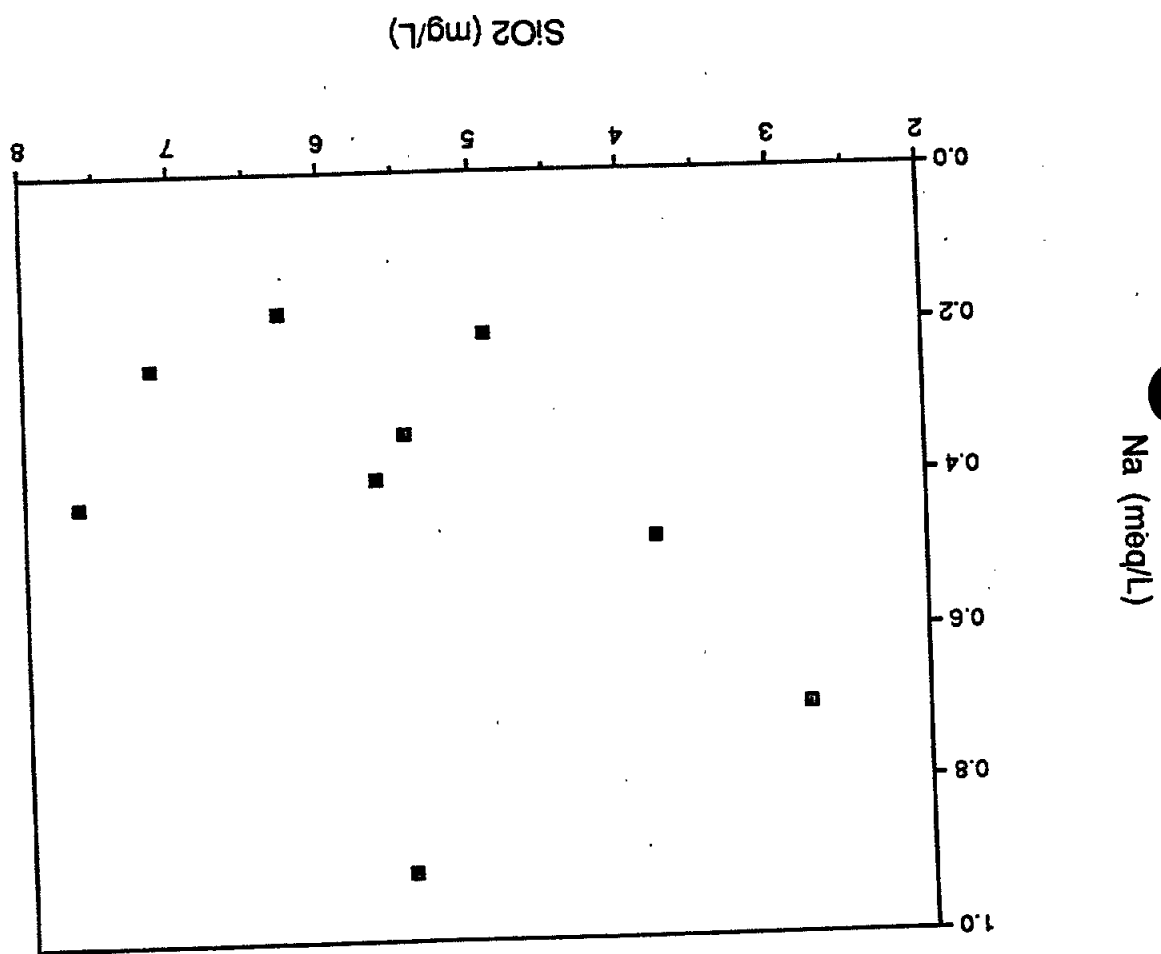
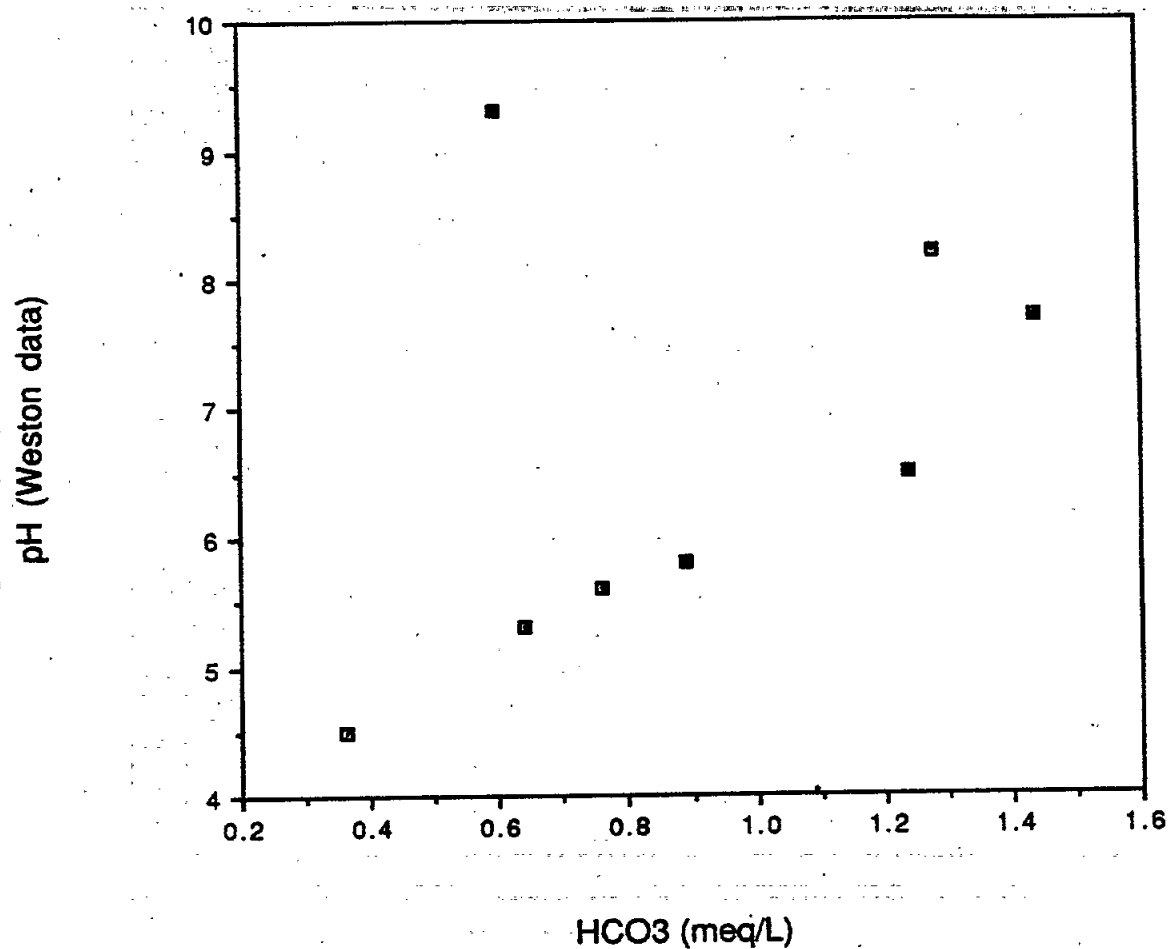


Figure 17. Na vs SiO<sub>2</sub> NaHCO<sub>3</sub>

AR300129

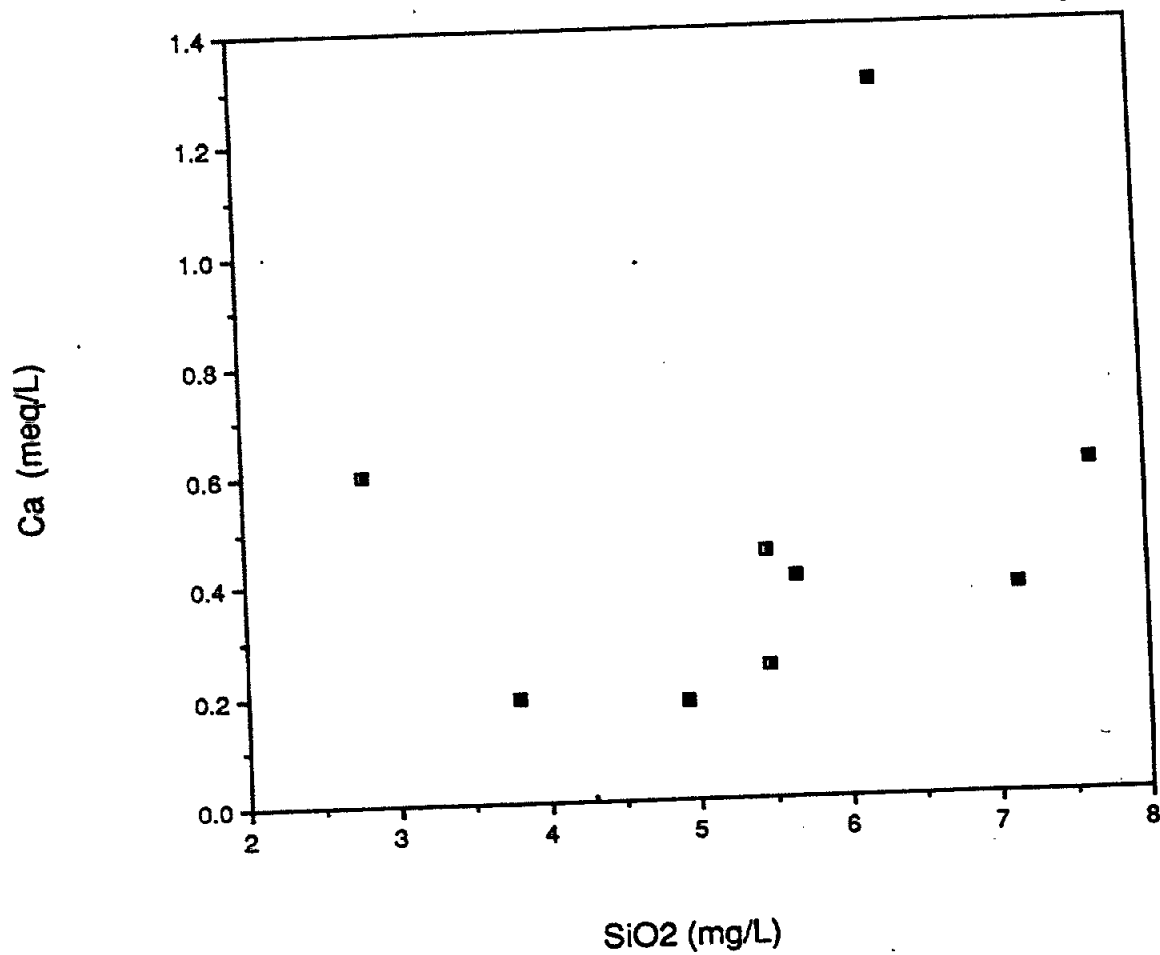


Figure 18. pH (Weston data) vs  $\text{HCO}_3^-$   $\text{NaHCO}_3$



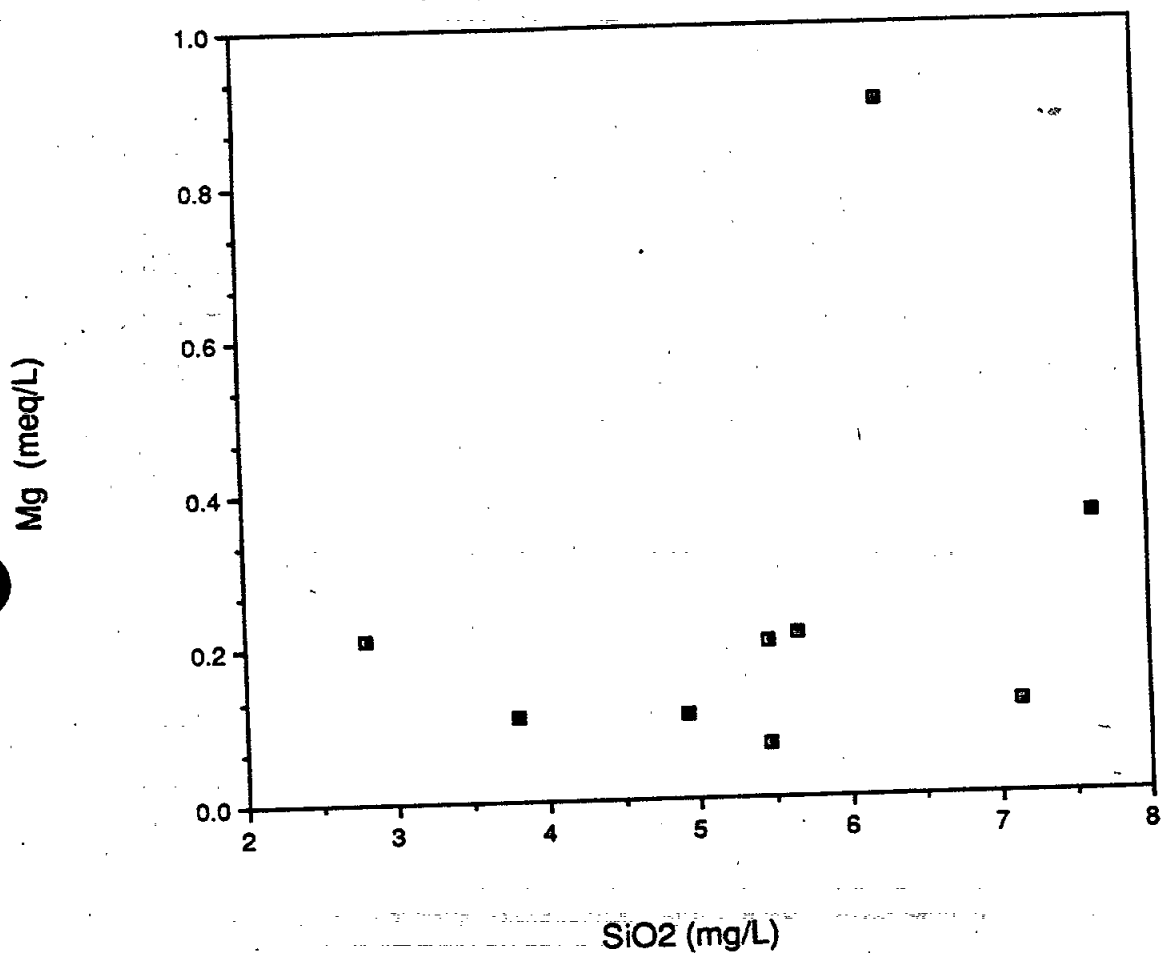
AR300130

Figurer 19. Ca vs SiO<sub>2</sub> NaHCO<sub>3</sub>



AR300131

Figure 20. Mg vs SiO<sub>2</sub> NaHCO<sub>3</sub>



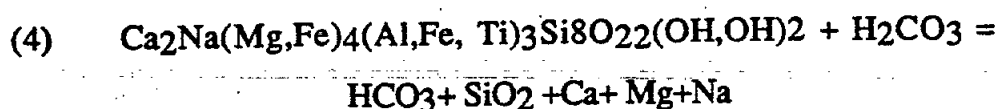
AR300132

## Chemical controls on Ca-Mg-Mixed waters

The Schoeller diagram (fig. 7) identified a set of waters as Ca-Mg-Mixed waters and represent waters from monitoring wells and domestic bedrock wells from Precambrian and Hardyston sandstone/conglomerate. Scatter diagrams were used to determine whether these waters represented a definable set of waters that are chemically distinct from other water types, determine whether there is internal chemical consistency within the group, and identify mineralogic reactions which may be controlling the water chemistry.

Ca-Mg-Mixed waters come from wells in Precambrian and Hardyston formations. The TDS for these waters range from 28 to 100 mg/l, the most dilute waters sampled. They contain equal concentrations of Ca and Mg and lesser concentrations of Na. Anion concentrations of  $\text{HCO}_3$ ,  $\text{SO}_4$ , and Cl are approximately equal. On the scatter diagrams different relationships are observed from the Na- $\text{HCO}_3$  water. In contrast to the Na- $\text{HCO}_3$  waters there are direct correlations between Ca vs  $\text{SiO}_2$  (fig. 21), Mg vs  $\text{SiO}_2$  (fig. 22), Na vs  $\text{SiO}_2$  (fig. 23),  $\text{HCO}_3$  vs  $\text{SiO}_2$  (fig. 24) and Ca vs Mg (fig. 25). There is no correlation between Na and  $\text{HCO}_3$  (fig. 26).  $\text{SO}_4$  does not correlate with any other chemical species (fig. 27). There were too few pH measurements made to determine correlations between pH and other chemical species. No correlations were observed between TCE and any chemical species.

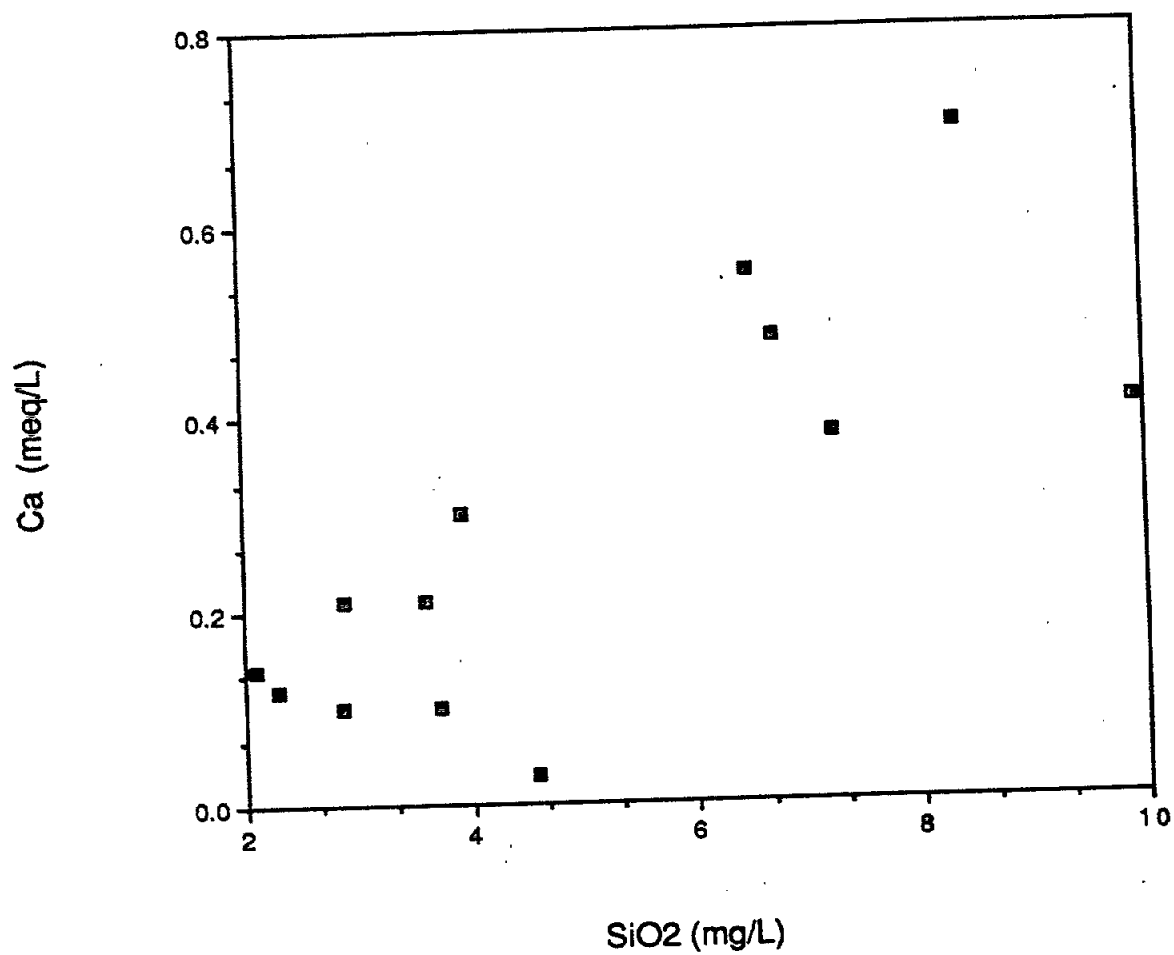
The increase in both  $\text{HCO}_3$  and  $\text{SiO}_2$  (fig. 24) probably results from water/rock reactions with silicate minerals. A reaction of soil  $\text{CO}_2$  with hornblende might look qualitatively as follows (4):



The increase in Mg (fig. 22) suggests reactions with mafic silicates (hornblende and biotite), which occur in the Precambrian rocks (Buckwalter, 1959). The lack of correlation between Na and  $\text{HCO}_3$  (fig. 26) suggests that calcite dissolution and cation exchange probably is not occurring.

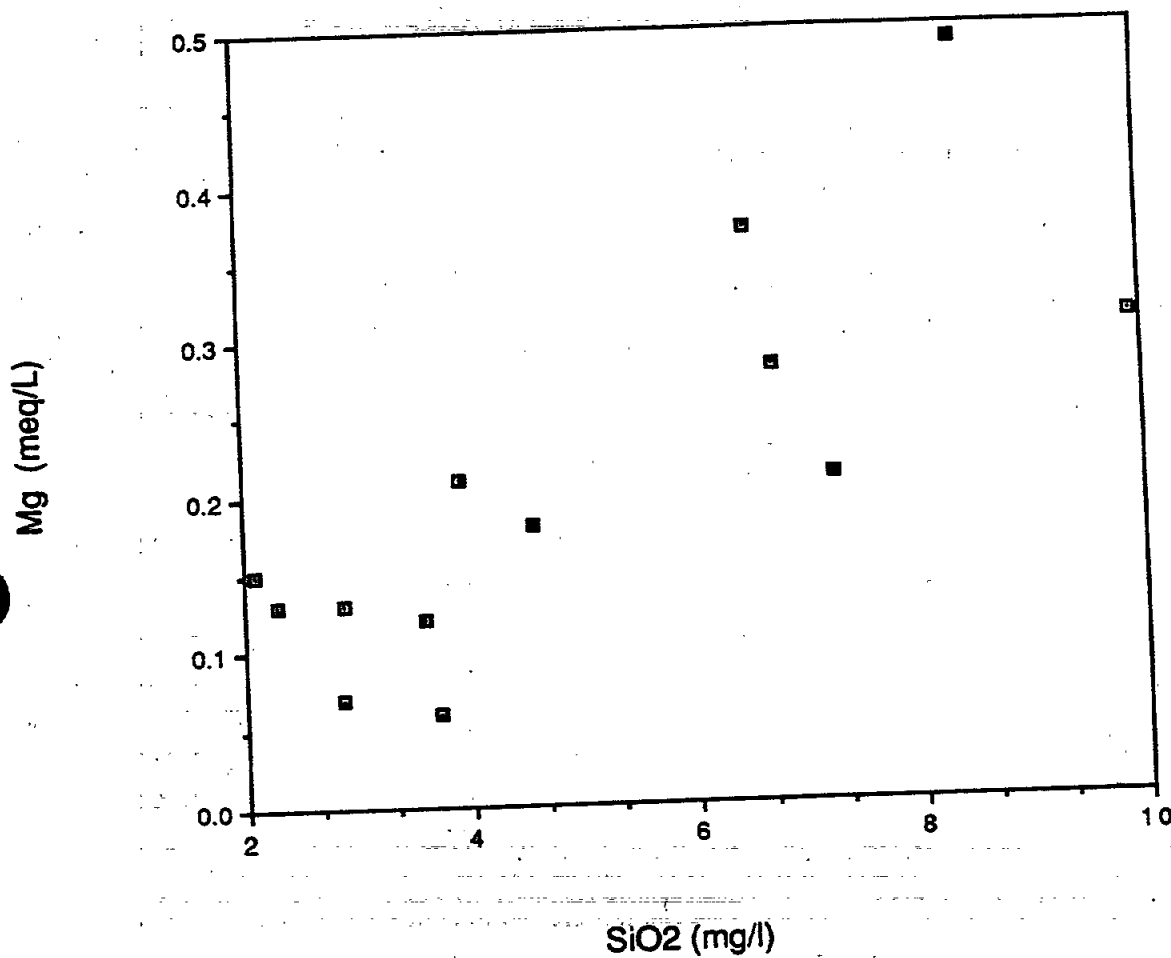
The identification of exact mineralogic reactions cannot be done with the limited data available for this study. It is more important to recognize that the chemical compositions of these Ca-Mg-Mixed waters (predominantly bedrock wells) appears chemical distinct from the Na- $\text{HCO}_3$  waters. These waters appear unique from the other two water types and appear to have chemical consistency.

Figure 21. Ca vs SiO<sub>2</sub> CaMgMixed



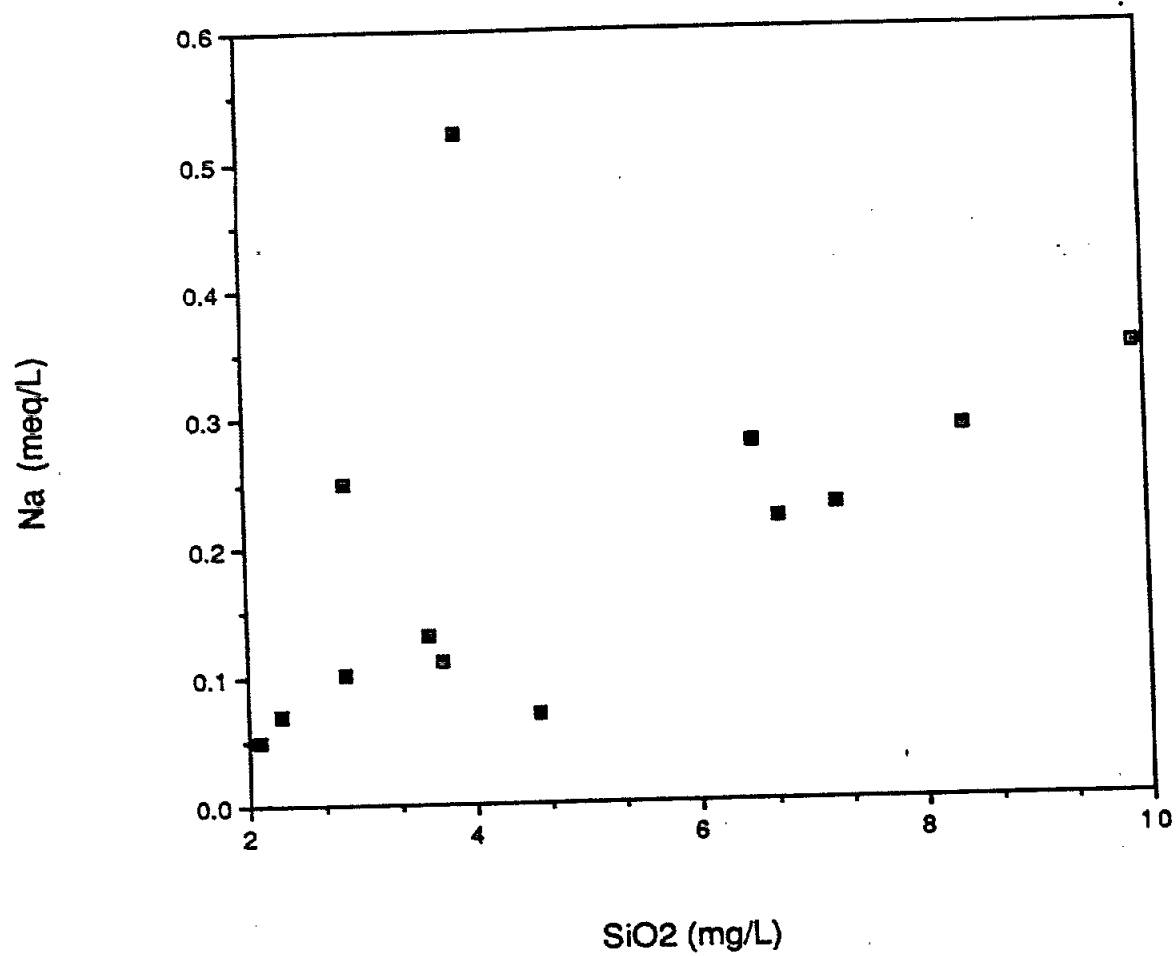
AR300135

Figure 22. Mg vs SiO<sub>2</sub> CaMgMixed



AR300136

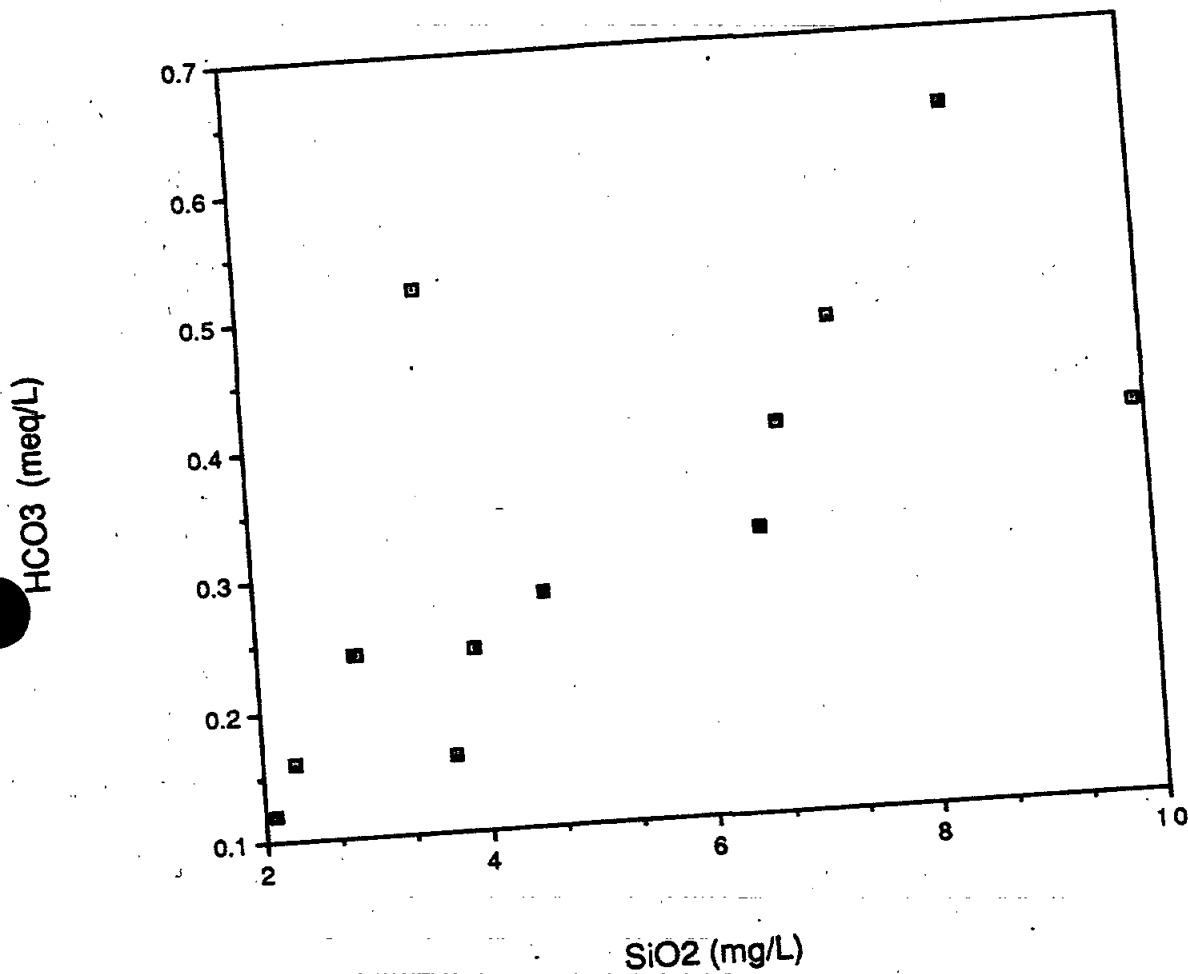
Figure 23. Na vs SiO<sub>2</sub> CaMgMixed



AR300137



Figure 24.  $\text{HCO}_3$  vs  $\text{SiO}_2$  CaMgMixed



AR300138

Figure 25. Ca vs Mg CaMgMixed

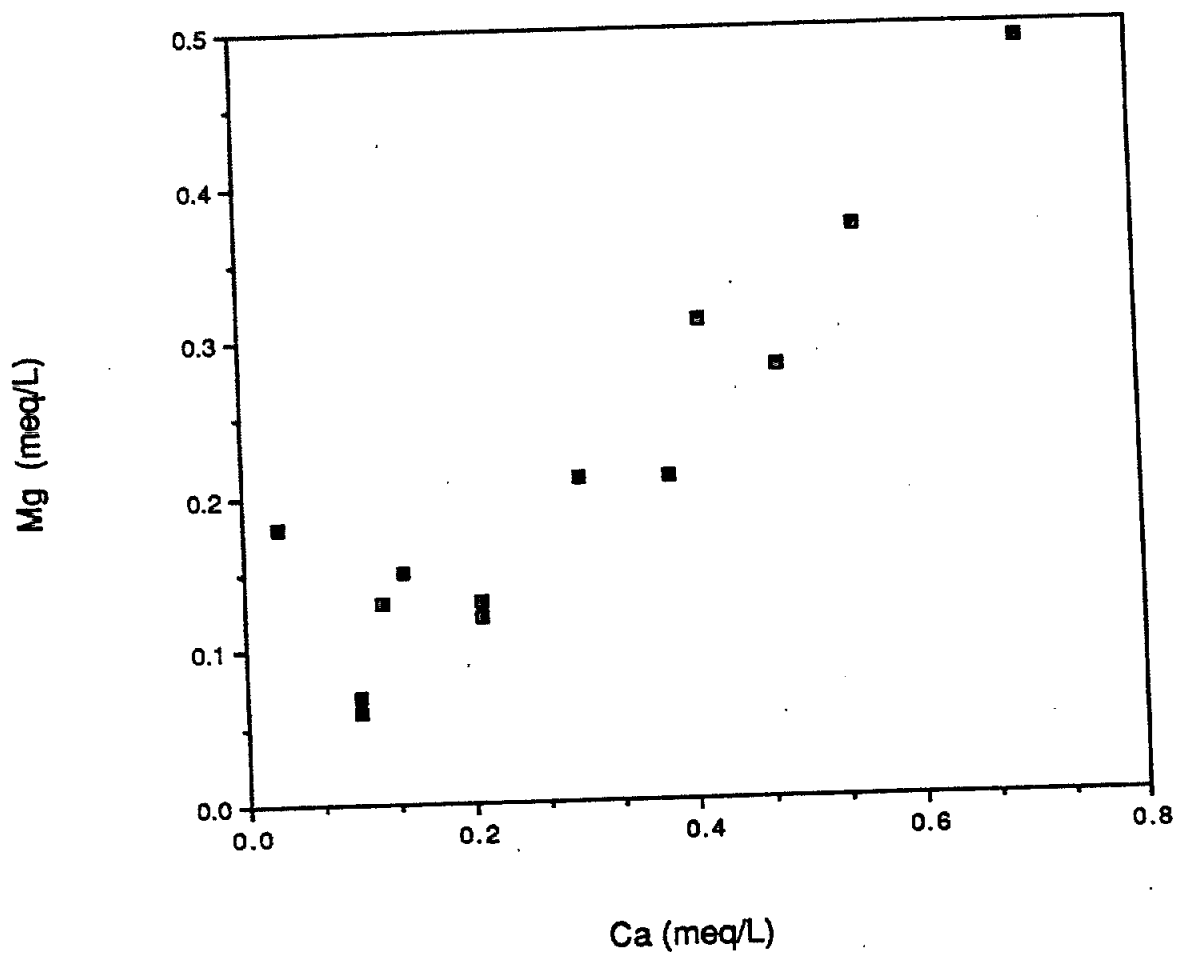
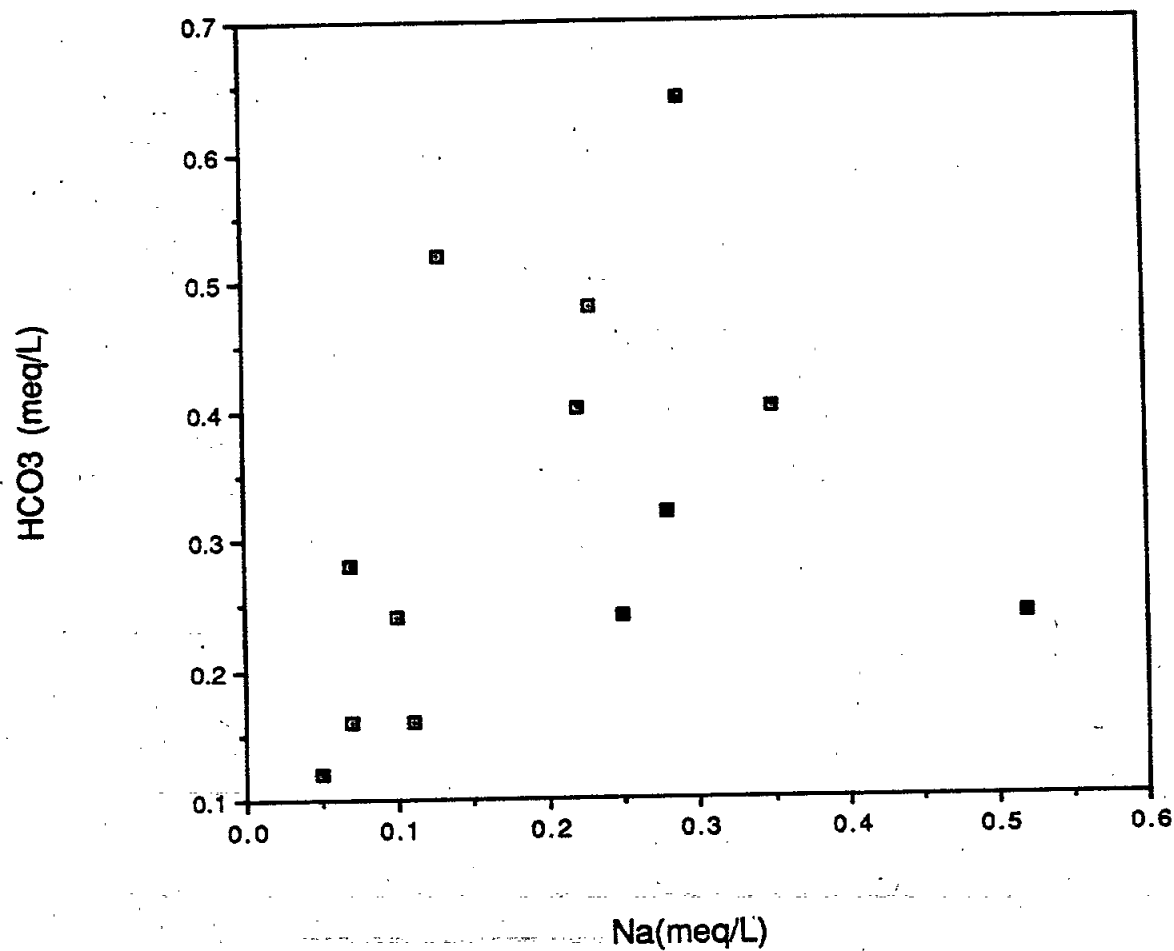
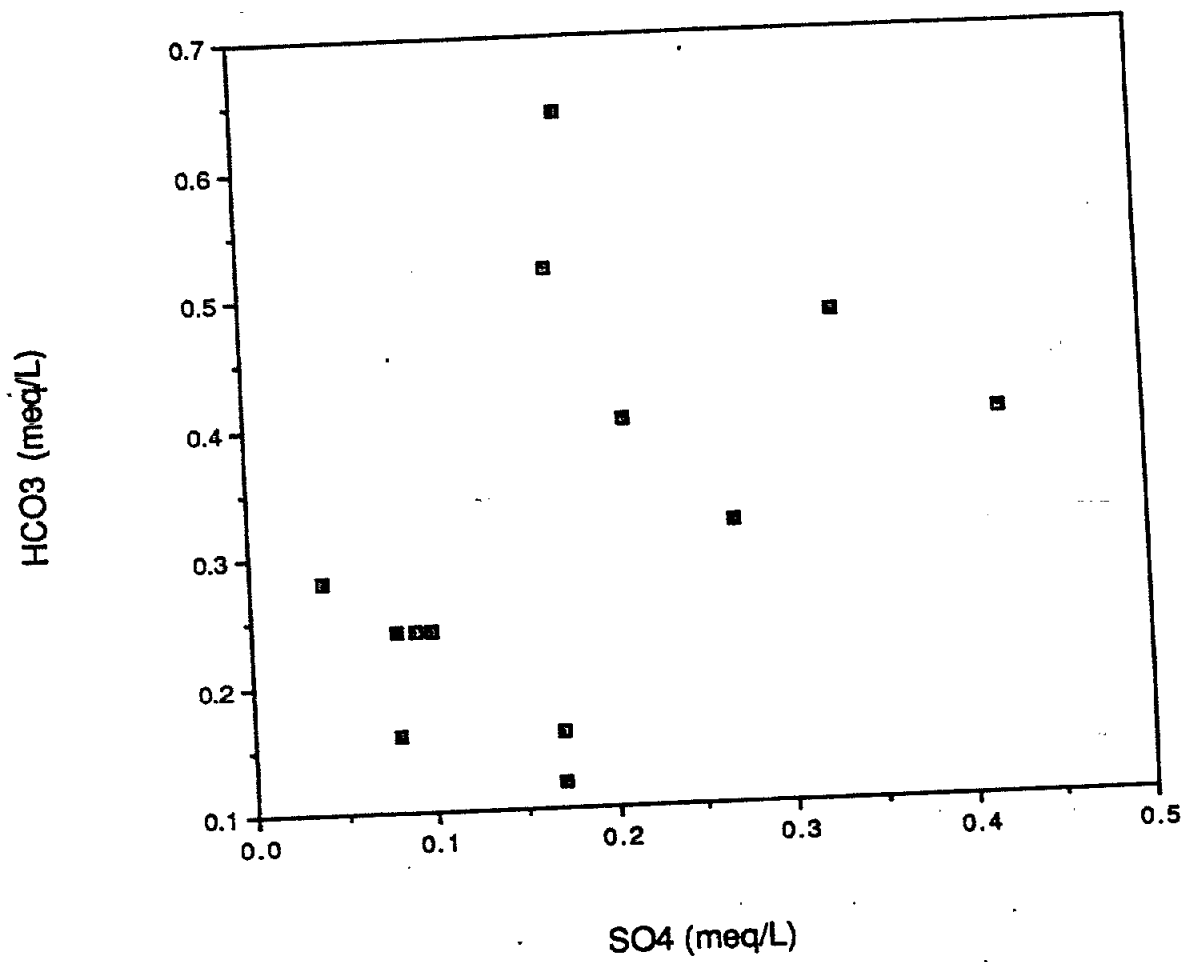


Figure 26. Na vs HCO<sub>3</sub> CaMgMixed



AR300140

Figure 27. HCO<sub>3</sub> vs SO<sub>4</sub> CaMgMixed



AR300141

## Chemical controls on Ca-Mg-HCO<sub>3</sub> waters

The Schoeller diagram (fig. 8) identified a set of waters as Ca-Mg-HCO<sub>3</sub> waters and represents waters from bedrock wells in the Tomstown carbonates. Scatter diagrams were used to determine whether these waters represented a definable set of waters that are chemically distinct from other water types, determine whether there is internal chemical consistency within the group, and identify mineralogic reactions which may be controlling the water chemistry.

The Ca-Mg-HCO<sub>3</sub> waters occur in the Tomstown carbonates. Total dissolved solids range from 75 - 350 mg/L, higher than either of the other two water types. Ca vs Mg (fig. 28), Ca vs HCO<sub>3</sub> (fig. 29) and Mg vs HCO<sub>3</sub> (fig. 30) show linear increases. Na vs SiO<sub>2</sub> (fig. 31) shows no correlation and HCO<sub>3</sub> vs SO<sub>4</sub> (fig. 32) shows a poor inverse relationship. Too few pH measurements were made for interpretation.

The Ca-Mg-HCO<sub>3</sub> compositions results from solution of calcite and/or dolomite (Eq. 5), which are more soluble than the Precambrian gneiss or Hardyston sandstones and quartzites. The cations are dominated by equal concentrations of Ca and Mg which suggest that the Tomstown carbonates are predominantly dolomite. Anions are dominated by HCO<sub>3</sub>.

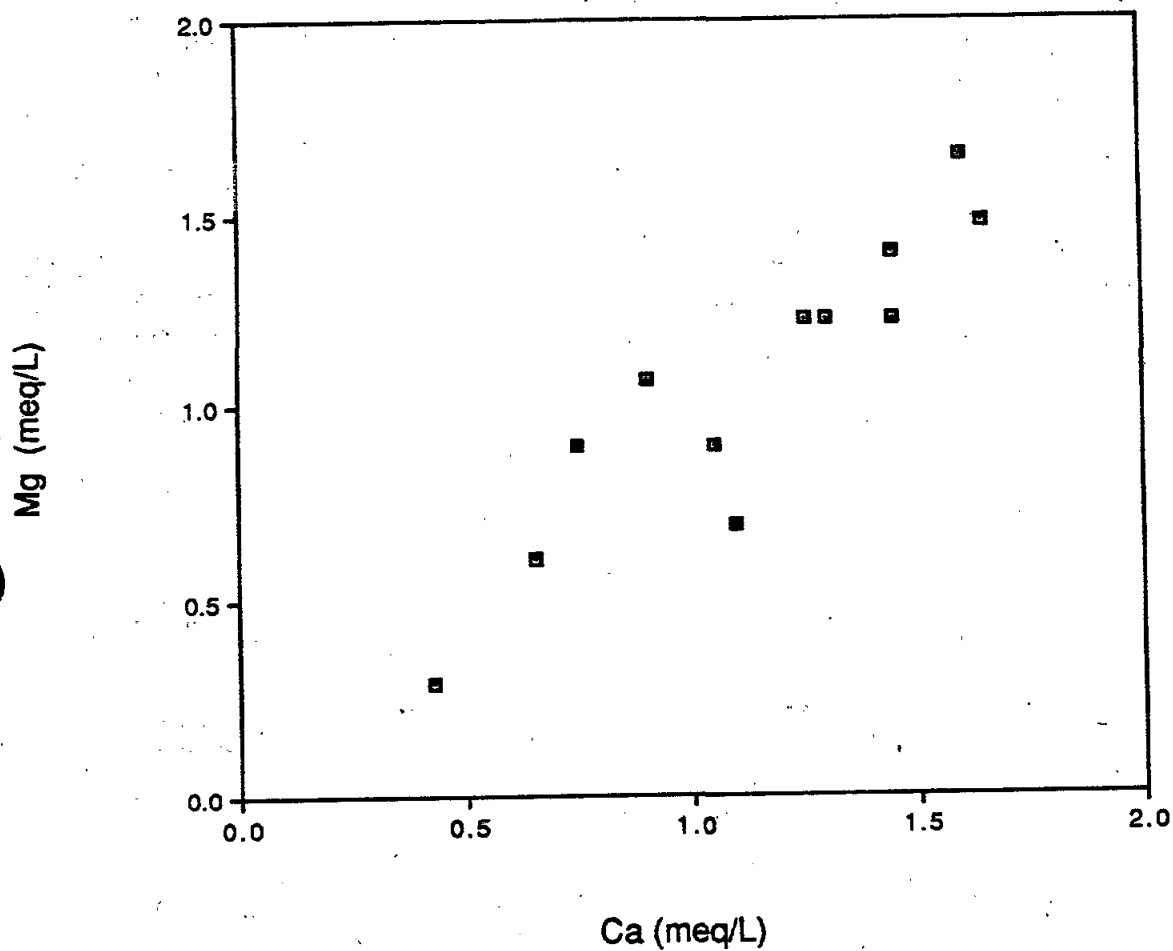


The low SiO<sub>2</sub> concentrations and lack of correlation with HCO<sub>3</sub> suggest silicate dissolution reactions are not important in the

Tomstown carbonate. Sulfur reactions (pyrite oxidation or gypsum solution) do not appear important either.

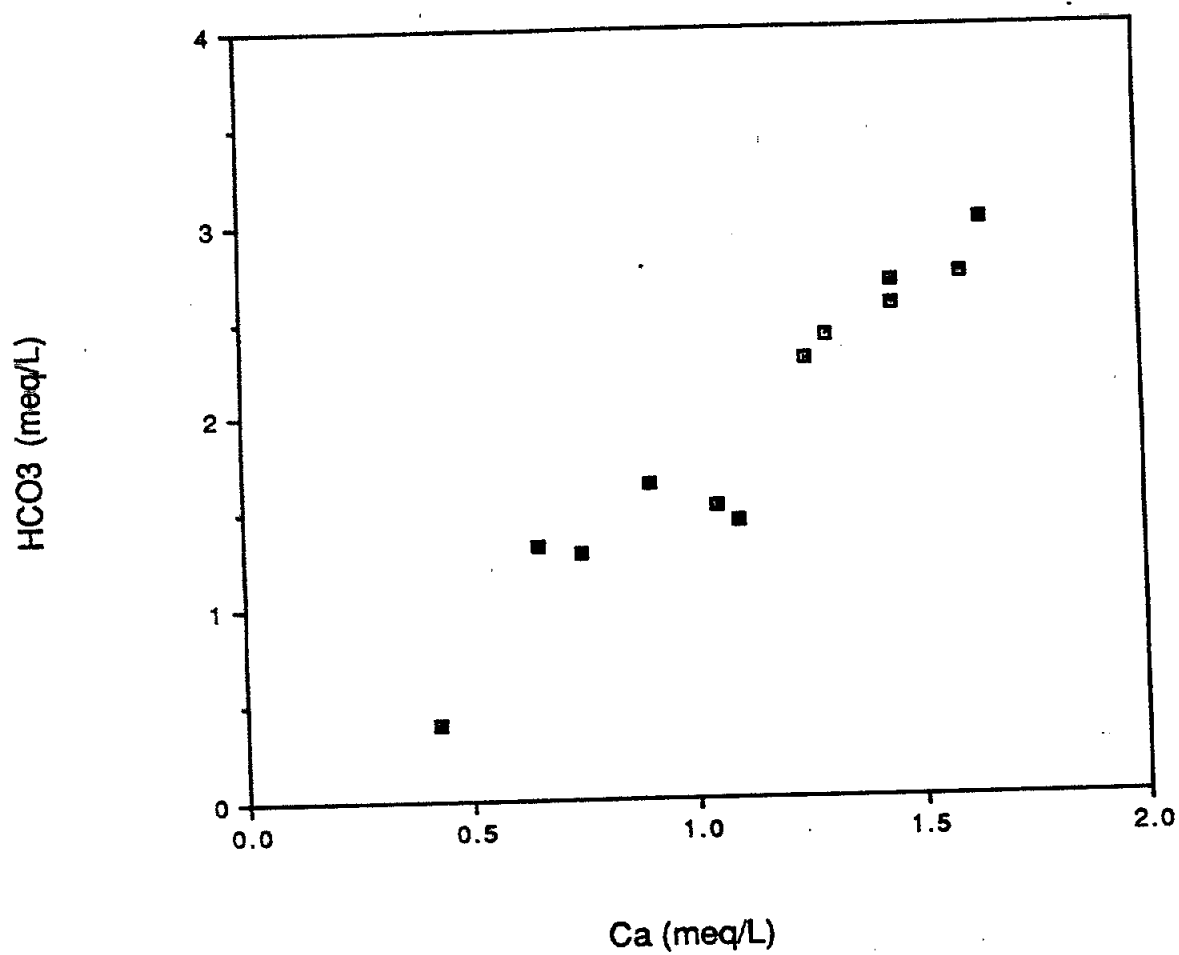
The identification of exact mineralogy within the Tomstown cannot be made with the limited data available for this study. It appears that the Tomstown carbonates contain significant dolomite beds, if not entirely a dolomite, based on the equal compositions of Ca and Mg. The chemical compositions of these Ca-Mg-HCO<sub>3</sub> waters are chemical distinct from the other waters, both in total dissolved solids and chemical composition. Recognizing this distinct chemical composition from the other water types will permit water well drillers and land owners to easily determine whether a well is producing from the Tomstown carbonates. These waters have internal chemical consistency, that is, they all appear to have undergone similar rock/water reactions.

Figure 28. Ca vs Mg  $\text{CaMgHCO}_3$



AR300144

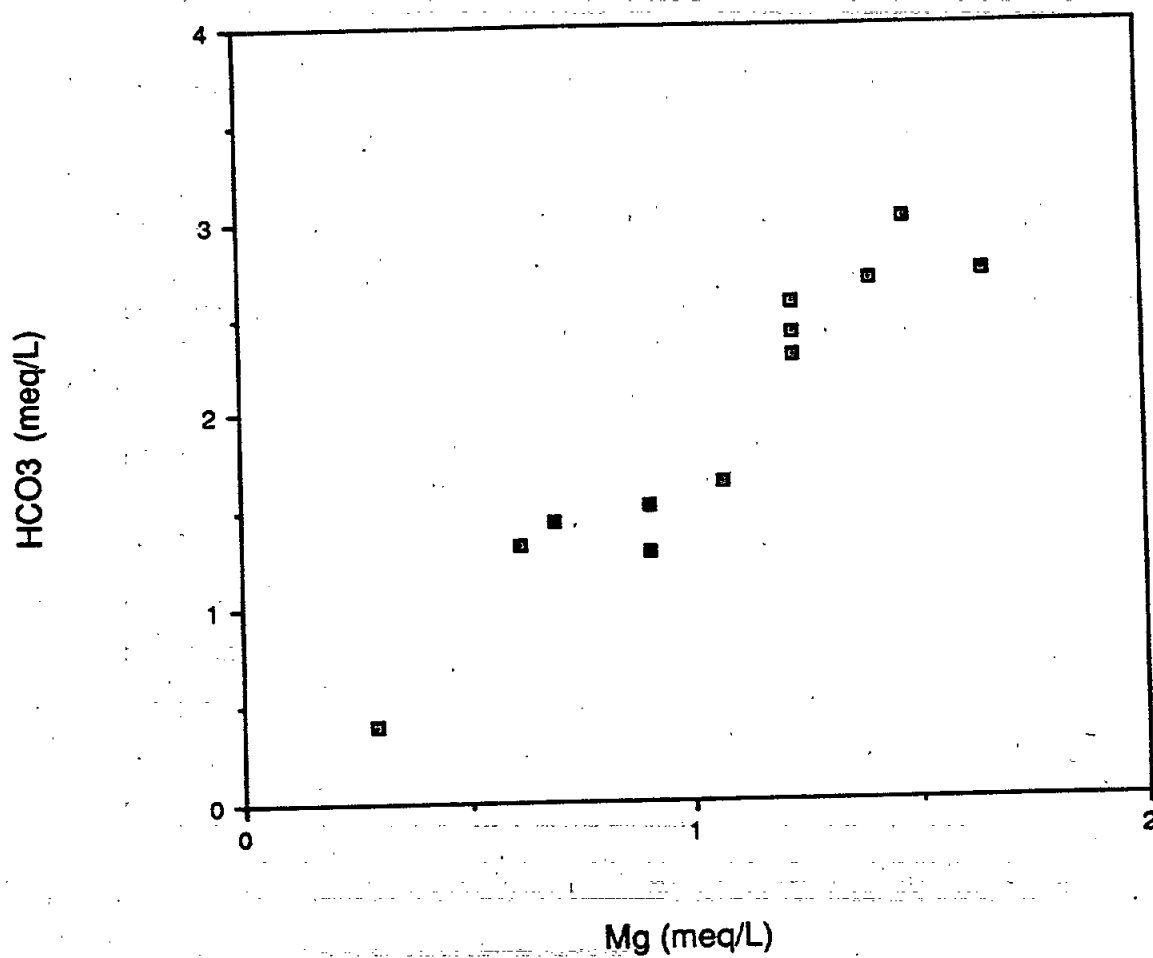
Figure 29. Ca vs HCO<sub>3</sub> CaMgHCO<sub>3</sub>



AR300145

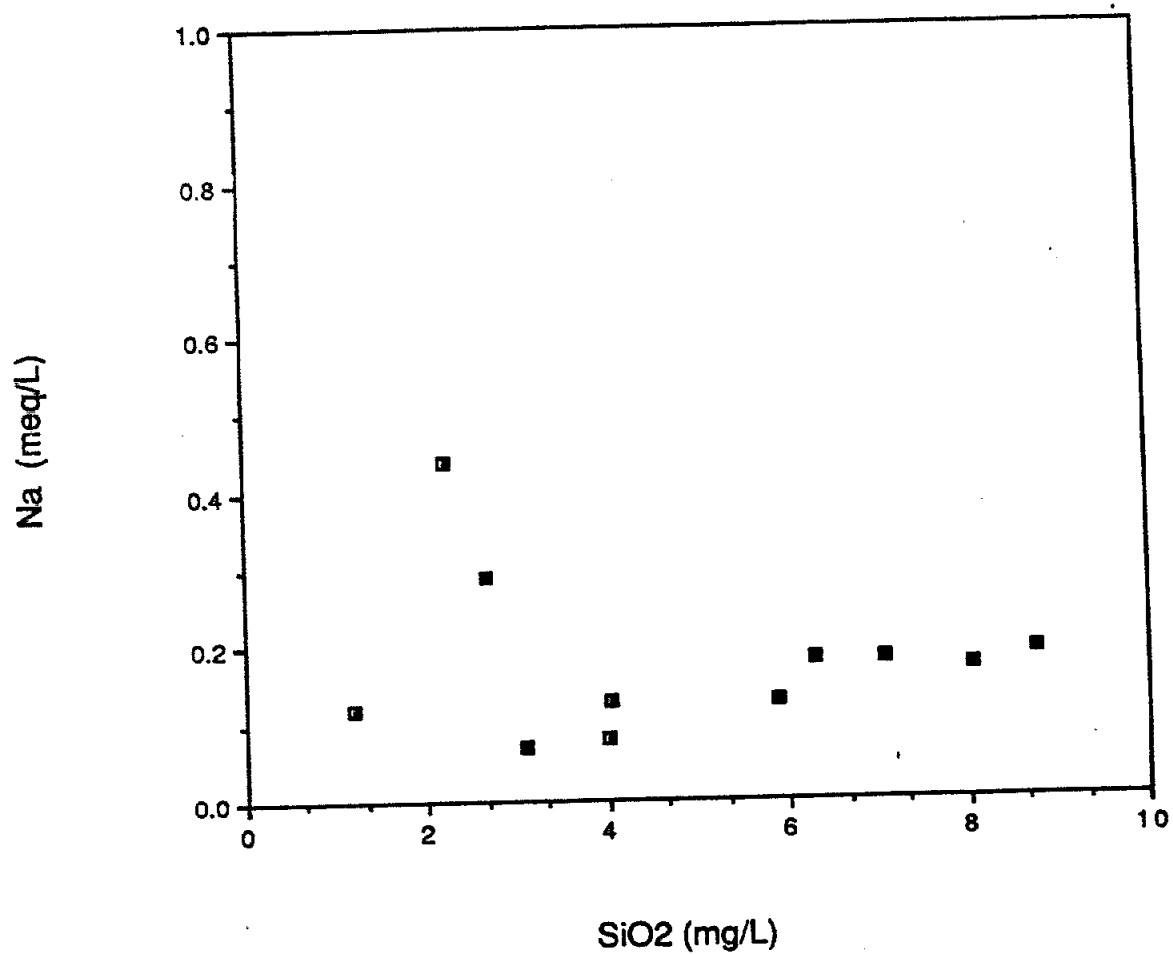


Figure 30. Mg vs HCO<sub>3</sub> CaMgHCO<sub>3</sub>



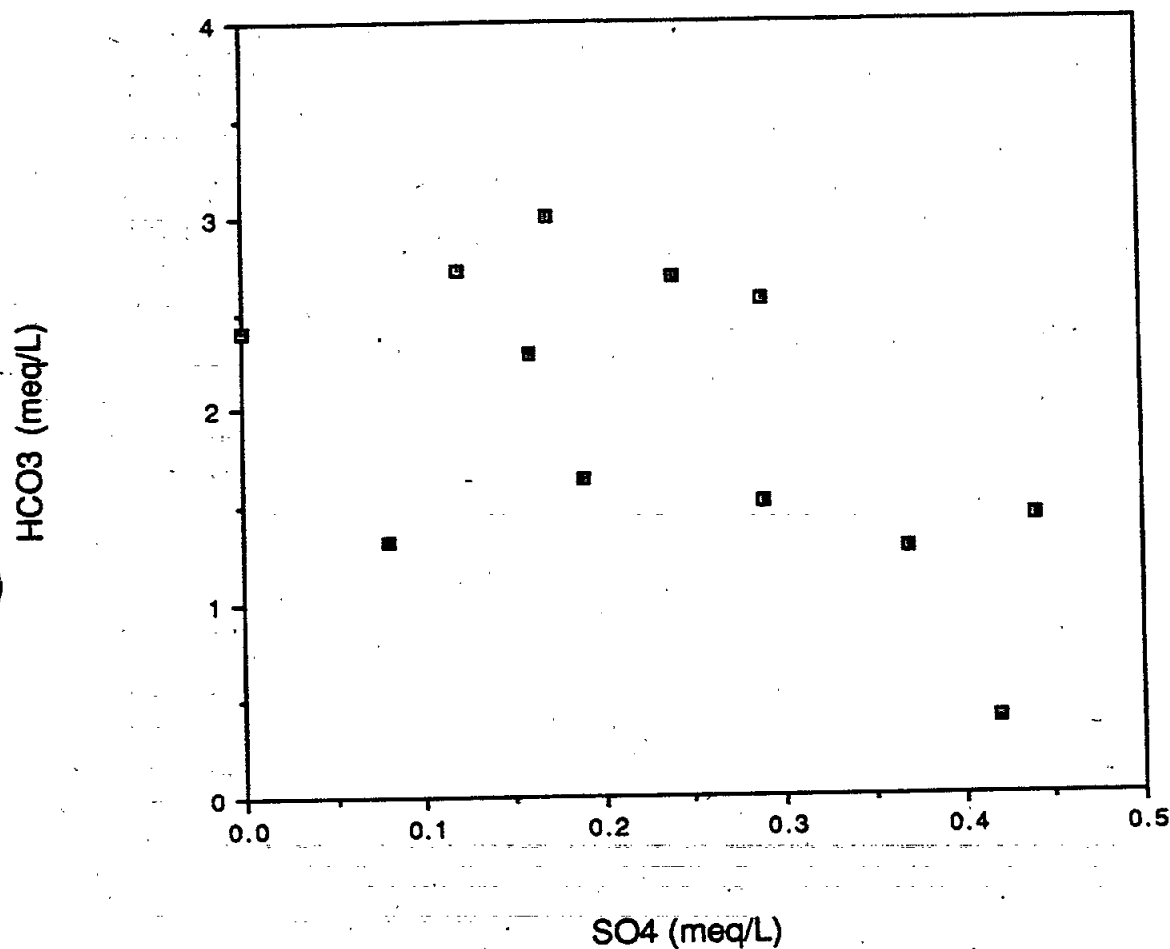
AR300146

Figure 31. Na vs SiO<sub>2</sub> Ca-Mg-HCO<sub>3</sub>



AR300147

Figure 32.  $\text{HCO}_3$  vs  $\text{SO}_4$  CaMg $\text{HCO}_3$



AR300148

## Mixing of waters

The previous sections have identified three different water chemistries, each of which may represent different hydrogeologic environments. The Na-HCO<sub>3</sub> waters are predominantly from the monitoring wells on Blackhead Hill; the Ca-Mg-Mixed waters occur in the Precambrian and Hardyston bedrock and overburden wells off of Blackhead Hill; and, the Ca-Mg-HCO<sub>3</sub> waters occur in the Tomstown carbonates. We can develop a better understanding of the movement of TCE away from a contamination source on Blackhead Hill determining if there has been an evolution of the chemical composition of the ground water from one water type to another which would indicate that ground water, and therefore TCE, flows from one hydrogeologic setting to another. Figure 45, a plot of well elevation vs water table, shows that the Na-HCO<sub>3</sub> waters have the highest elevation on the potentiometric surface, then the Ca-Mg-Mixed waters and the Ca-Mg-HCO<sub>3</sub> waters have the lowest potentiometric position. Hydrologically water should flow from the Na-HCO<sub>3</sub> to the Ca-Mg-Mixed to the Ca-Mg-HCO<sub>3</sub> waters. Two pathways are important to identify. 1) Is there flow of the Na-HCO<sub>3</sub> waters from the top of the hill to the Ca-Mg-Mixed waters in the bedrock wells? 2) Is there ground-water flow from the Precambrian and Hardyston formations into the Tomstown carbonates?

## Evolution of Na-HCO<sub>3</sub> waters to Ca-Mg-Mixed waters

Na-HCO<sub>3</sub> waters and Ca-Mg-HCO<sub>3</sub> waters from figures 33, 34, and 35 appear to be different types of waters. The Ca-Mg-Mixed water appears to have evolved independent from the Na-HCO<sub>3</sub>

water. Total dissolved solids concentrations for the Na-HCO<sub>3</sub> waters are higher than for the Ca-Mg-Mixed waters (fig. 33). Similarly plots of HCO<sub>3</sub> vs SiO<sub>2</sub> (fig. 34) and Na vs SiO<sub>2</sub> (fig. 35) shows that SiO<sub>2</sub> for the Ca-Mg-HCO<sub>3</sub> water has evolved independent of the Na-HCO<sub>3</sub> waters and from initial concentrations lower than the Na-HCO<sub>3</sub> water type. In regards to the migration of TCE, four options need to be considered. 1) TCE contaminated ground water in the Blackhead Hill region may not be migrating into Precambrian/Hardyston ground waters off the hill. TCE within possibly low-permeability materials on the hill may still be contained. 2) TCE contaminant migration may be by a separate immiscible phase. The high concentrations of TCE may be moving as a non aqueous phase independent of ground-water flow. 3) There may be additional locations where TCE contamination has occurred. 4) Differences in chemical composition between Ca-Mg-Mixed and Na-HCO<sub>3</sub> water may be artificially caused by well construction problem. There are enough differences between the chemical compositions of these two water types to suggest that they are different regardless of Na and HCO<sub>3</sub> concentrations

#### Evolution of Ca-Mg-Mixed waters to Ca-Mg-HCO<sub>3</sub> waters

Ca-Mg-HCO<sub>3</sub> waters appear to have evolved chemically from Ca-Mg-Mixed waters. Plots of Mg vs TDS (fig. 36) and Ca vs TDS (fig. 37) show a continual evolution from the Ca-Mg-Mixed waters to the the Ca-Mg-HCO<sub>3</sub> waters. This flow path is to be expected. The carbonate rocks occupy the valleys, the topographic low parts of the area and potentiometric lows of the hydrogeologic setting, as well as having presumably higher permeabilities. Ground water typically

flows from topographic and potentiometric highs to topographic and potentiometric lows and from low permeability to more permeable formations. In regards to the migration of TCE, TCE should be expected to migrate from the Precambrian and Hardyston formations into the Tomstown carbonates.

Evolution of Na-HCO<sub>3</sub> waters to Ca-Mg-HCO<sub>3</sub> waters

Ground-water flow from Na-HCO<sub>3</sub> to Ca-Mg-HCO<sub>3</sub> may also be occurring. Plots of Mg vs TDS (fig. 36), Ca vs TDS (37), HCO<sub>3</sub> vs TDS (fig. 40) for these waters show a continual chemical evolution as observed between Ca-Mg-Mixed and Ca-Mg-HCO<sub>3</sub>. The correlation is poorer for SO<sub>4</sub> vs TDS (fig. 38) and Na vs TDS (fig. 39) and therefore flow from the Na-HCO<sub>3</sub> water type to the Ca-Mg-HCO<sub>3</sub> water type is less convincing from these data.

Figure 33. Na vs TDS for  $\text{NaHCO}_3$  and CaMgMixed waters.  
The CaMgMixed waters do not appear to  
have chemically evolved from the  $\text{NaHCO}_3$  water.

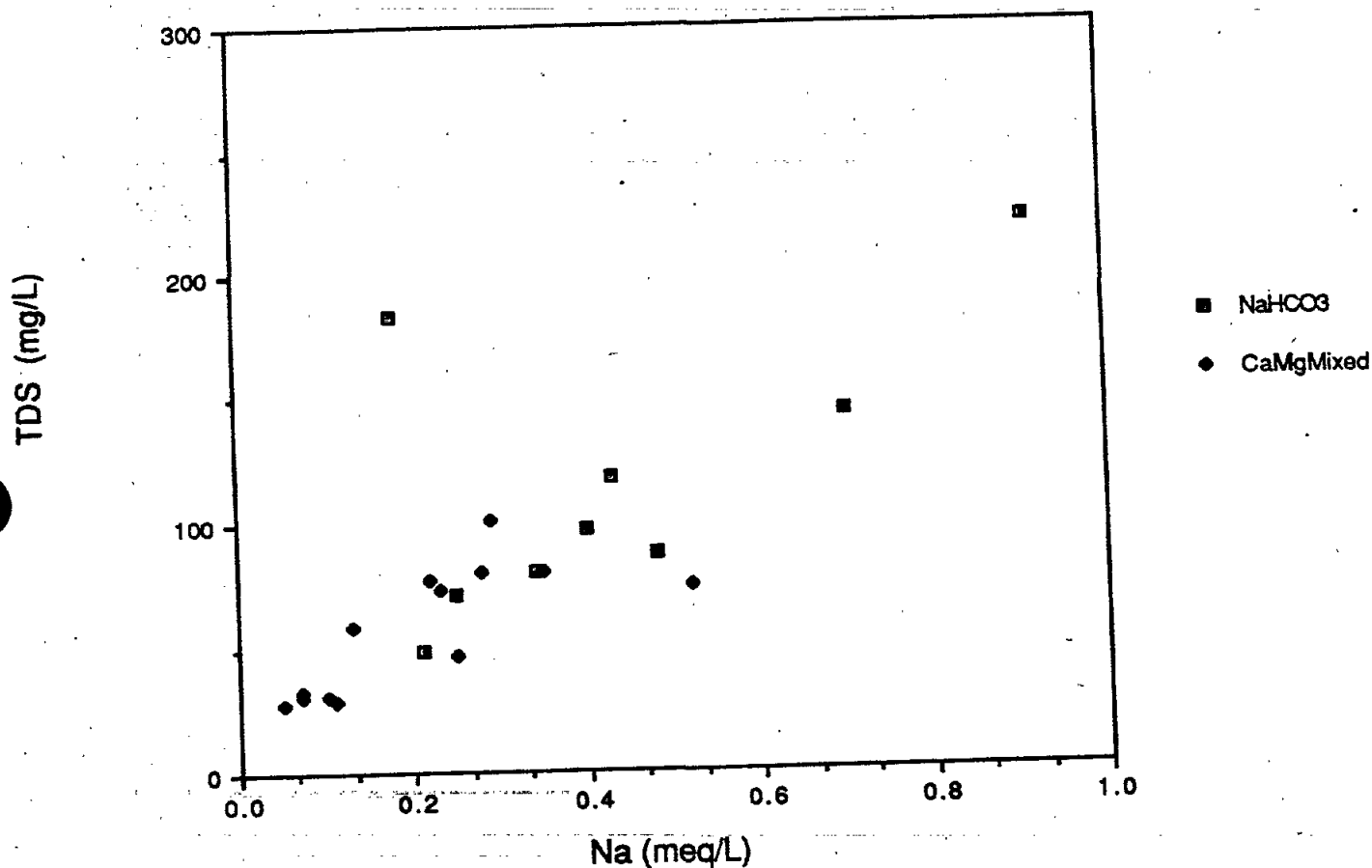
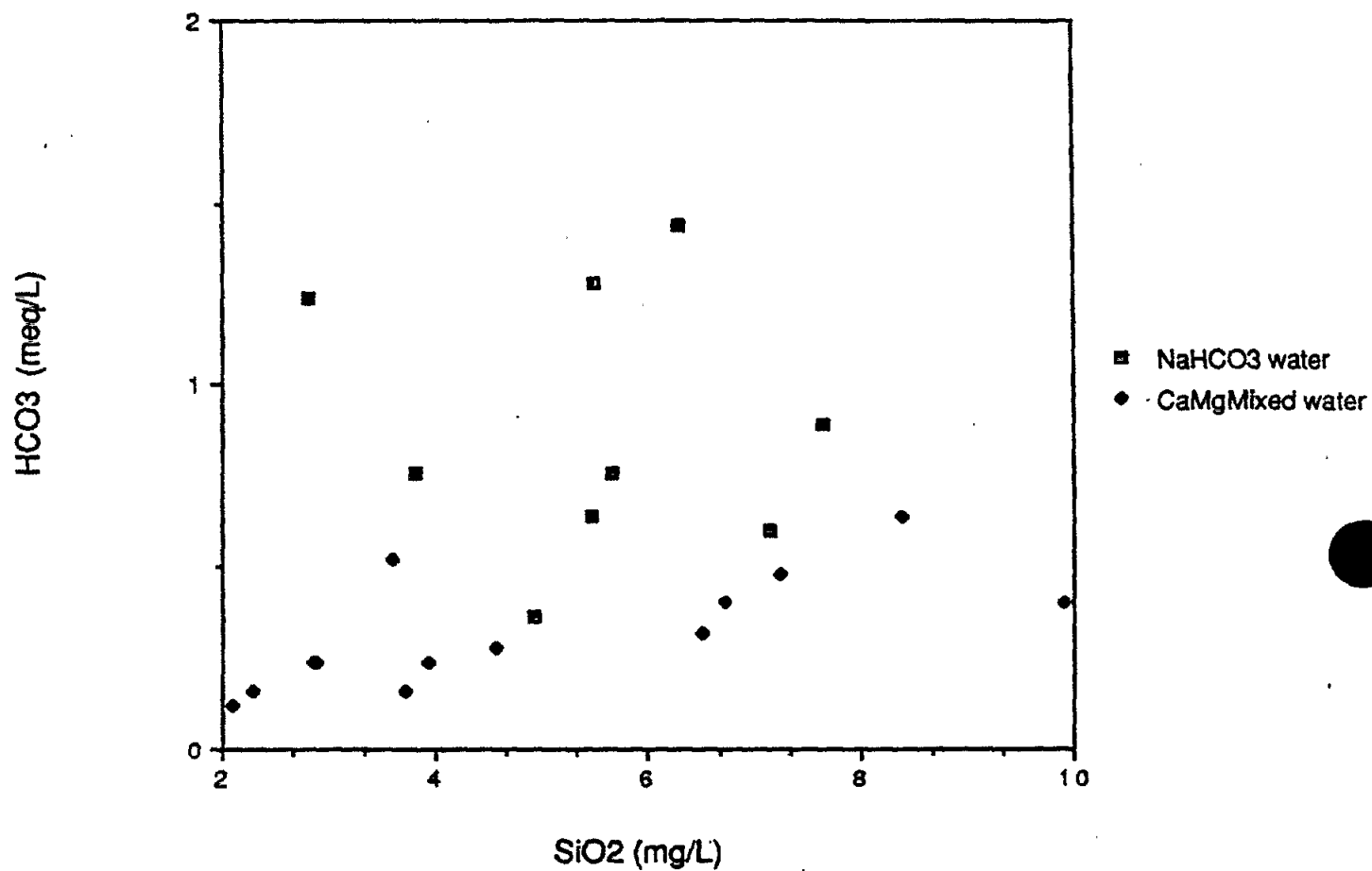


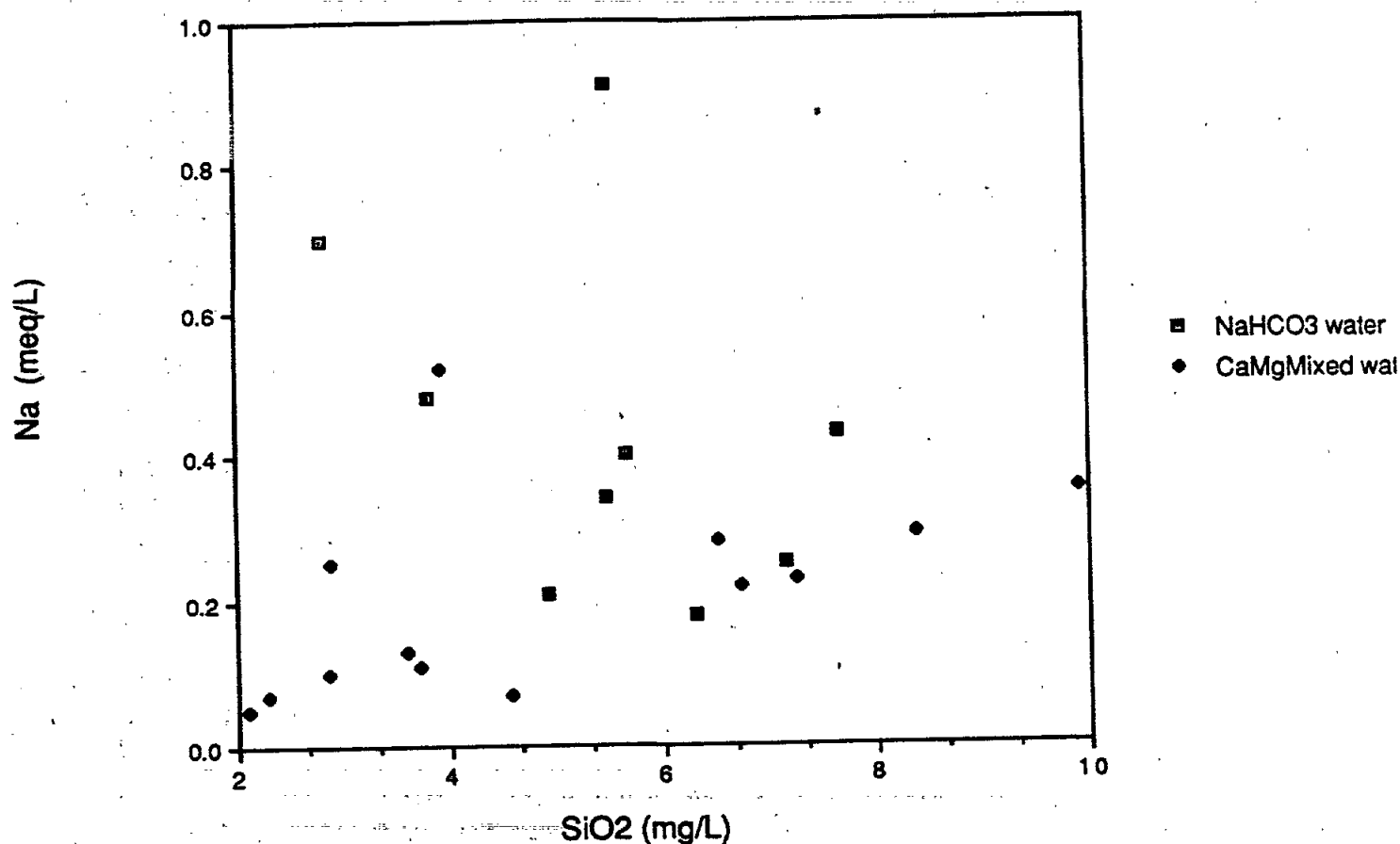
Figure 34.  $\text{HCO}_3$  vs  $\text{SiO}_2$  for  $\text{NaHCO}_3$  and CaMgMixed waters. CaMgMixed waters do not appear to evolve from the  $\text{NaHCO}_3$  waters



AR300153

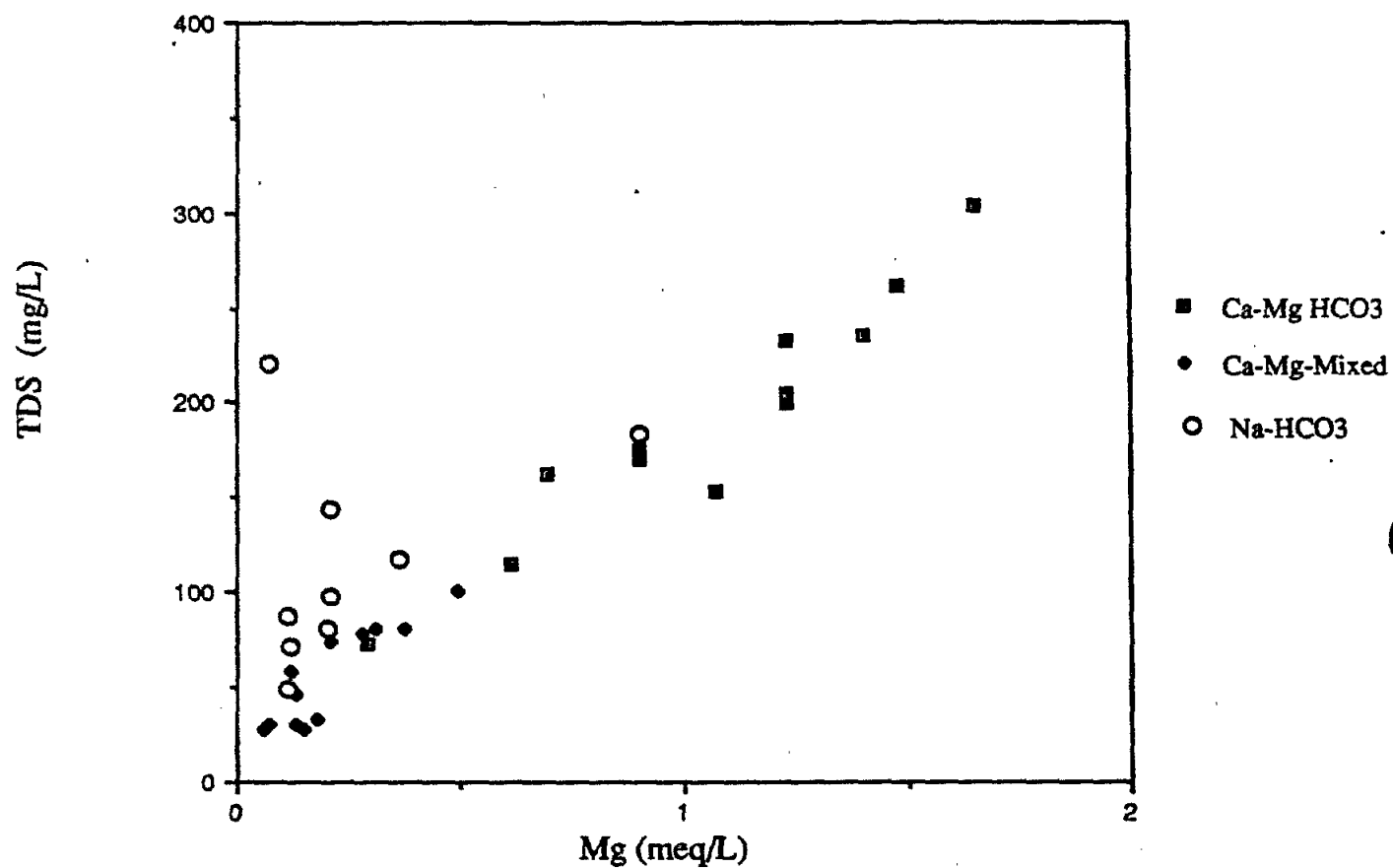


Figure 35. Na vs SiO<sub>2</sub> for NaHCO<sub>3</sub> and CaMgMixed waters.  
The CaMgMixed water does not appear to have evolved from NaHCO<sub>3</sub> water.



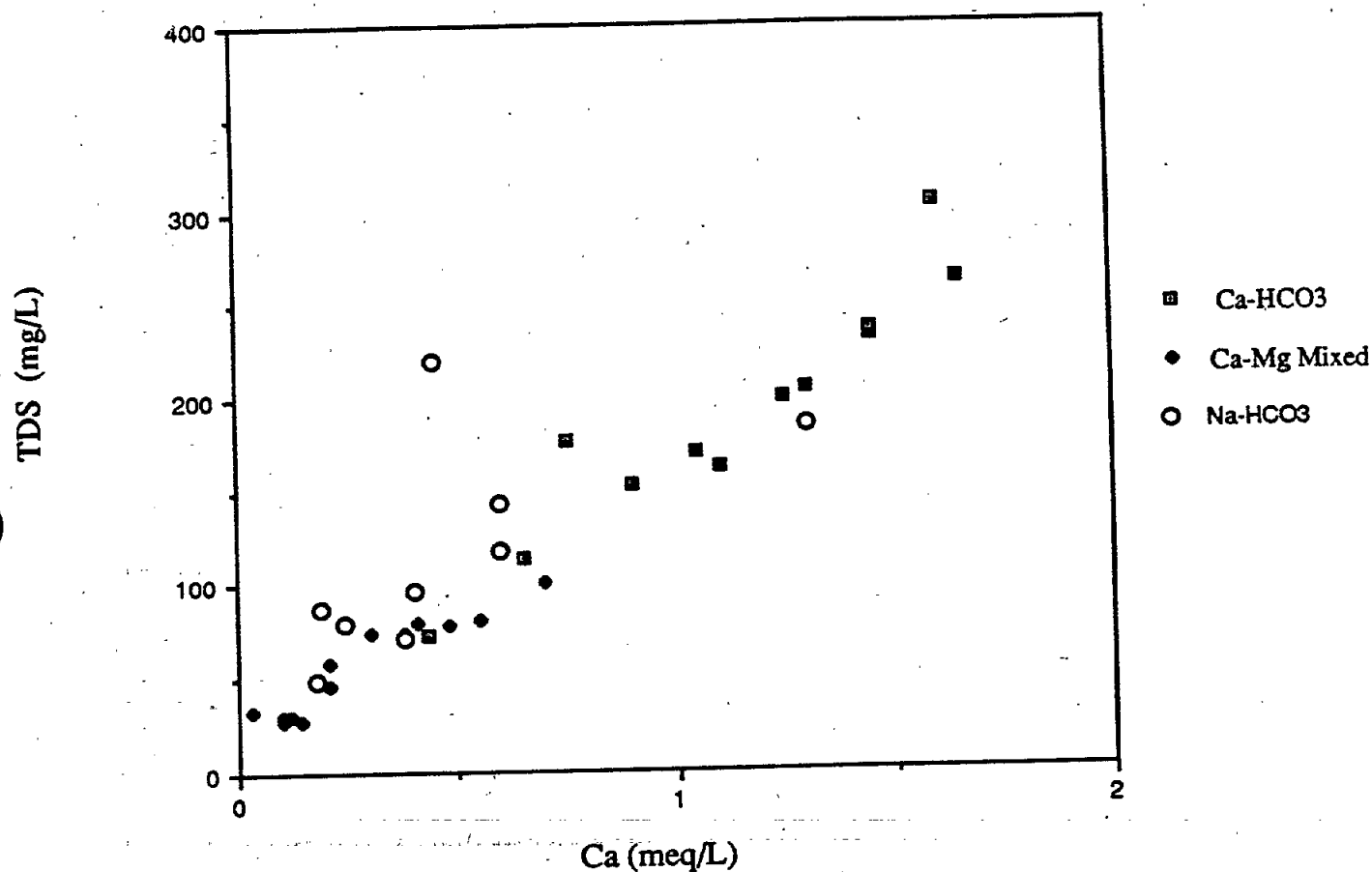
AR300154

Figure 36. Flow from Ca-Mg-Mixed and  
Na-HCO<sub>3</sub> to Ca-Mg-HCO<sub>3</sub> Water  
TDS vs Mg



AR300155

Figure 37. Flow from Ca-Mg-Mixed and  
Na-HCO<sub>3</sub> to Ca-Mg-HCO<sub>3</sub> Water  
TDS vs Ca



AR300156

Figure 38. Flow from Ca-Mg-Mixed and  
Na-HCO<sub>3</sub> to Ca-Mg-HCO<sub>3</sub> Water  
TDS vs SO<sub>4</sub>

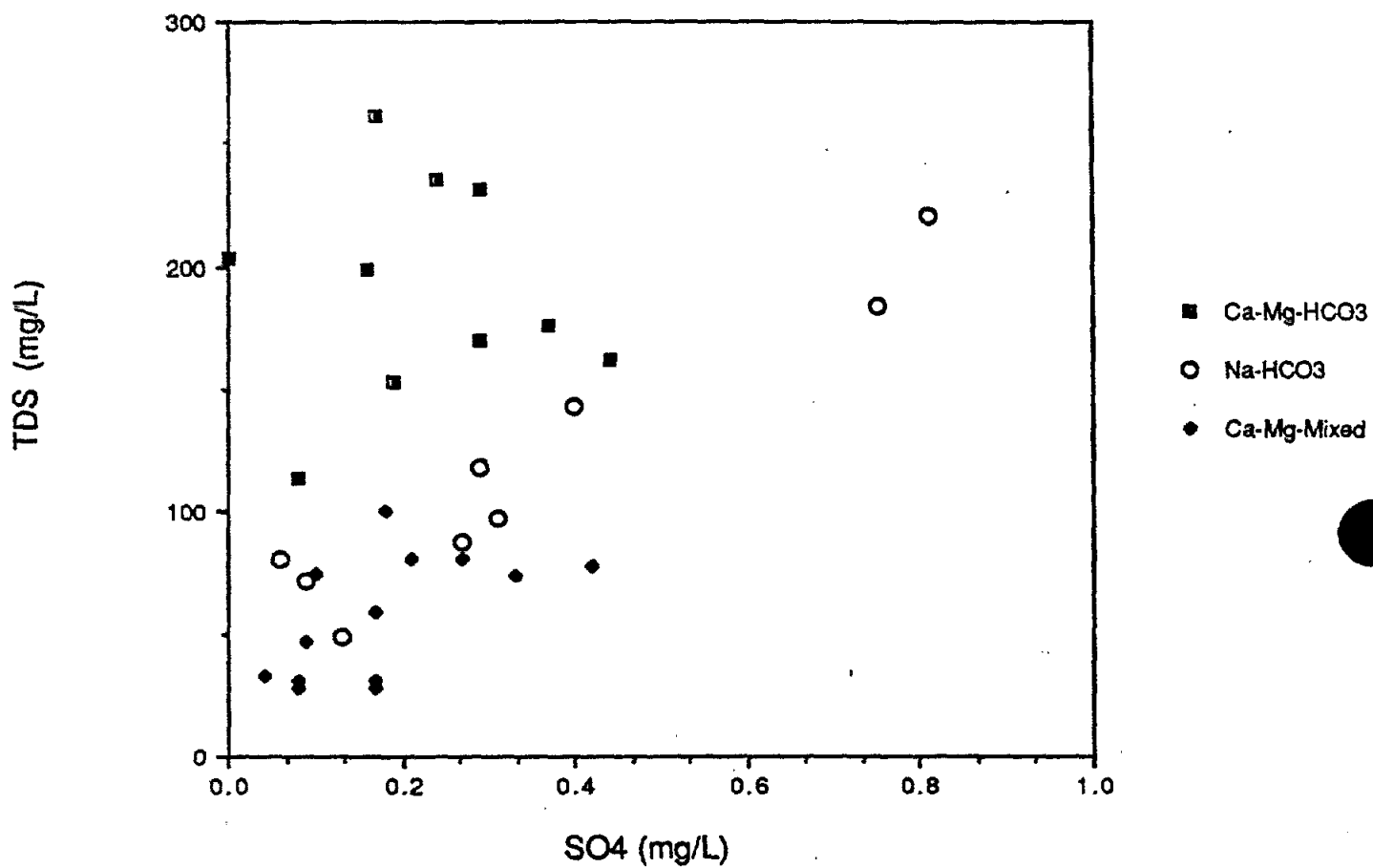


Figure 39. Flow from Ca-Mg-Mixed and  
Na-HCO<sub>3</sub> to Ca-Mg-HCO<sub>3</sub> Water  
TDS vs Na

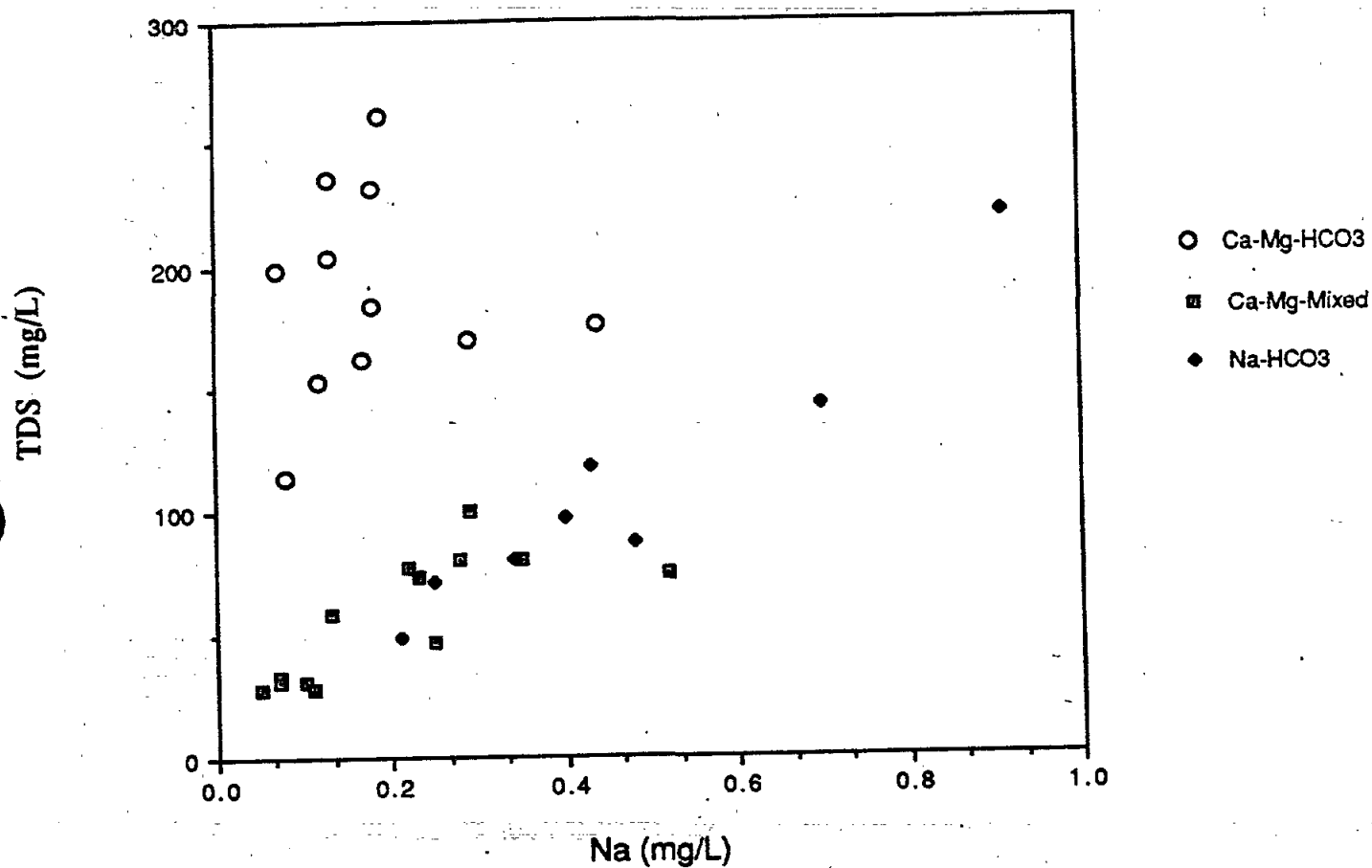
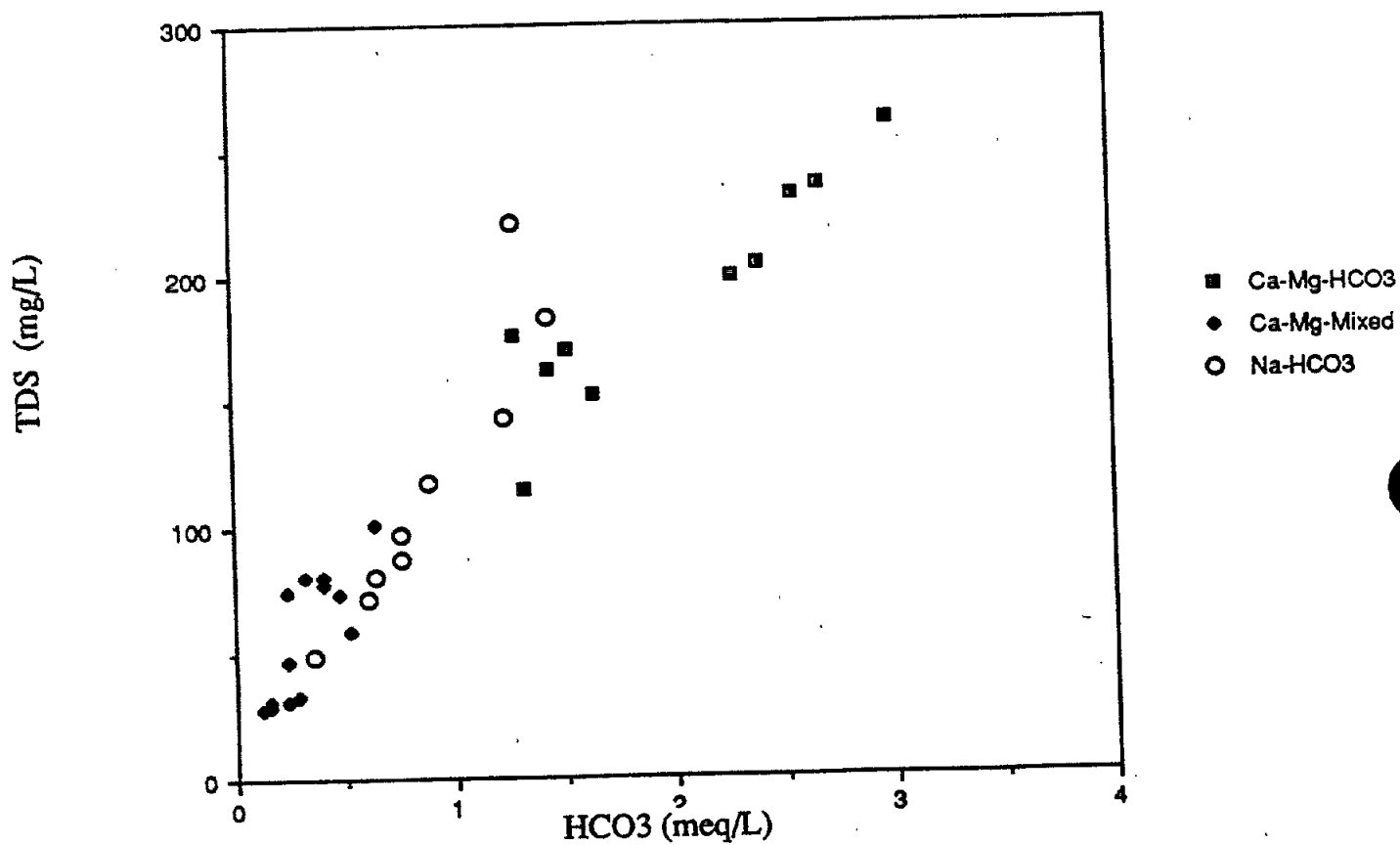


Figure 40. Flow from Ca-Mg-Mixed and  
Na-HCO<sub>3</sub> to Ca-Mg-HCO<sub>3</sub> water  
TDS vs HCO<sub>3</sub>



## Identification of Carbonate Producing Zones in Water Wells by Water Chemistry: Evidence for Thrust Faulting

Water in five wells (Johnson, Karlosky, L. Miller, MW 2R, and MW 4R) have Ca-Mg-HCO<sub>3</sub> compositions, but are located in areas where the surface geology is not limestone. The Johnson well could be located in out crop of either Tomstown carbonate or Hardyston sandstone; the exact location of the well with respect to the geology can not be made with the available maps. Both Karlosky and MW 4R appear to be producing from carbonates beneath the Hardyston Formation. The lithologic log for MW 4R penetrated carbonates in the bottom of the well. The L. Miller well appears to be producing from the carbonates beneath gneiss. No completion information, however, is available for this well for confirmation. MW 2R, a monitoring well drilled for this study, has a Ca-Mg-HCO<sub>3</sub> type water, but the lithologic log shows no carbonates. MW 2DR, a deeper test well next to MW 2R does not show carbonates either. The presence of Paleozoic carbonates beneath gneiss (L. Miller well?) and Hardyston sandstone strongly argues for a thrust zone between the Tomstown limestone and older rocks. These permeable carbonates should be present at depth in other parts of this area and might provide a low TCE water for future water supplies.

## TCE Distribution

Highest TCE concentrations are in the Na-HCO<sub>3</sub> and the Ca-Mg-Mixed waters with minor concentrations (relatively speaking) in the Ca-Mg-HCO<sub>3</sub> waters (figs. 41 and 42). 1988 data (Table 3) was used in preference to 1987 data because more values were available. Comparison of 1987 and 1988 data does not show significant changes.

Plots of TCE vs HCO<sub>3</sub> (figs. 43 and 44) shows the separation of the Na-HCO<sub>3</sub> and the Ca-Mg-Mixed water types. Both water types have been contaminated, but based on the water chemistry the Ca-Mg-Mixed waters can not result from migration of waters from the Na-HCO<sub>3</sub> waters.

Lower concentrations of TCE are found in the Ca-Mg-HCO<sub>3</sub> waters. The carbonates probably function as a hydrologic sink for the regional ground water flow. Any TCE contamination from the Na-HCO<sub>3</sub> and the Ca-Mg-Mixed waters are probably greatly diluted within the carbonate aquifer.

The highest concentrations of TCE in domestic wells are found at the intersection of the Camp Mensch Mill Road and the Forgedale Road (K. Metzler, J. Metzler, Johnson, Wetzel, Berry wells). Contamination is found in both Ca-Mg-HCO<sub>3</sub> and Ca-Mg-Mixed waters. It is interesting to note that monitoring wells MW3OB and MW3DOB have lower TCE concentrations than domestic wells located further from Blackhead Hill. Buckwalter (1959) shows two faults and a formation contact which trend east-northeast. These zones may be



important permeability zones for migration of TCE from on the top of Blackhead Hill to the contaminated area in the valley.

Generally lower levels of TCE are observed in predominantly carbonate wells (Karlosky, Swavey, Sobjack, MW6R, and MW7DR) located to the south of Blackhead Hill where MW1R is located. (The Finegan well does have 1280 ug/L). MW1R has the highest TCE concentrations observed in the ground water (19,630 ug/l). There may be a strong anisotropy which has prevented major contamination of wells to the south of the MW1R site.

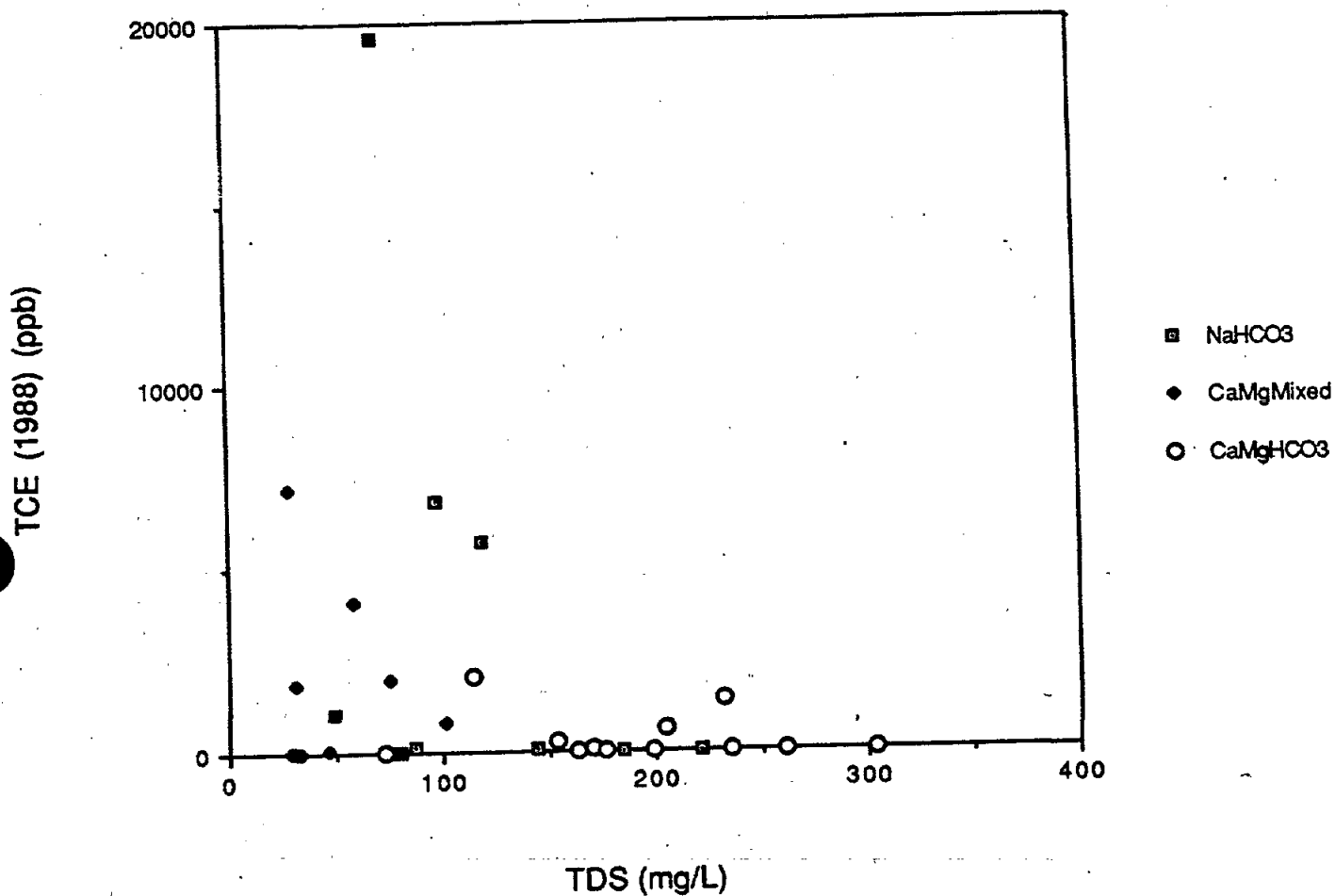
TCE concentrations in the Wagner and MW8R carbonate wells are surprisingly high. The Wagner well is located on the west side of the Perkiomen Creek from the major suspected contamination source. Perkiomen Creek should act as a discharge zone and contamination across this discharge zone would not be expected. Other wells on the west side of Perkiomen Creek (Camp Mensch Hill, Fronheiser and Grater) show no TCE Contamination. TCE contamination in MW8R is surprising because of its long distance from suspected contamination sources. There are several carbonate wells between MW8R and Blackhead Hill which show no or lower TCE concentrations. This random variation in TCE in the carbonates suggests karst permeability and ground-water flow in discrete conduits.

## TCE distribution

location	TCE(ug/L) (88)	Chemical Group	Surf. Geol.	well elev. (ft)	Well depth (ft)	DTW(ft)(7/88)	WT(ft) (7/88)
1	MW1R	19630	Na-HCO3	bp	162	35	814
2	K. Metzler	7221	Ca-Mg-Mixed	Chm	257	59	627
3	MW1.20B	6845	Na-HCO3	bp,Chm	44	43	840
4	MW1.10B	5748	Na-HCO3	bp	41	35	820
5	MW5R	4064	Ca-Mg-Mixed	Chm, bp	302	42	645
6	MW4R	2047	Ca-Mg-HCO3	Chm	237	62	618
7	MW4OB	1960	Ca-Mg-Mixed	Chm	21	7	675
8	Moyer	1830	Ca-Mg-Mixed	Chl	125	48	620
9	Wagner	1414	Ca-Mg-HCO3	OCc			
10	MW10B	1027	Na-HCO3	bp	56	28	822
11	G. Miller	771	Ca-Mg-Mixed	bp			
12	Johnson	586	Ca-Mg-HCO3	Chm, OCc	172	49	620
13	MW8R	259	Ca-Mg-HCO3	OCc	123	16	583
14	MW3DOB	117	Na-HCO3	bp	70	37	669
15	MW30B	88	Na-HCO3	bp	23	21	681
16	MW5DOB	73	Ca-Mg-Mixed	Chm, bp	103	58	631
17	MW6R	35	Ca-Mg-HCO3	OCc	101	53	593
18	MW7DR	32	Ca-Mg-HCO3	OCc	124	52	591
19	Sobjack	26	Ca-Mg-Mixed	Chl	125	49	651
20	MW7R	24	Ca-Mg-HCO3	OCc	95	52	592
21	L. Miller	4	Ca-Mg-HCO3	bp			
22	MW2R	4	Na-HCO3	bp	51	30	862
23	MW2DR	3	Na-HCO3	bp	305	26	864
24	Crum	2	Ca-Mg-Mixed	Chl	58	21	636
25	Hausman	0	Ca-Mg-HCO3	OCc			
26	Karalosky	0	Ca-Mg-HCO3	OCc	300	46	589
27	Swavey	0	Ca-Mg-HCO3	OCc	85		
28	MW7OB	0	CaMgNaHCO3	OCc	56	52	593
29	Bechtel	0	Ca-Mg-Mixed	bp	104	20	887
30	camp Mensch	0	Ca-Mg-Mixed	bp	202	19	760
31	Geissinger	0	Ca-Mg-Mixed	Chm	220	39	707
32	Hill	0	Ca-Mg-Mixed	OCc	85		
33	Stephens	0	Ca-Mg-Mixed	bp			
34	MW6OB	0	Ca-Mg-Mixed	OCc	41	26	620
35	MW2.10B	0	Na-HCO3	bp	60	45	889

AR300163

Figure 41. TCE concentrations (1988) versus TDS for CaMgMixed, NaHCO<sub>3</sub> and CaMgHCO<sub>3</sub> waters



AR300164

Figure 42. TCE concentrations (1988) versus HCO<sub>3</sub> for NaHCO<sub>3</sub>, CaMgMixed, and CaMgHCO<sub>3</sub> waters

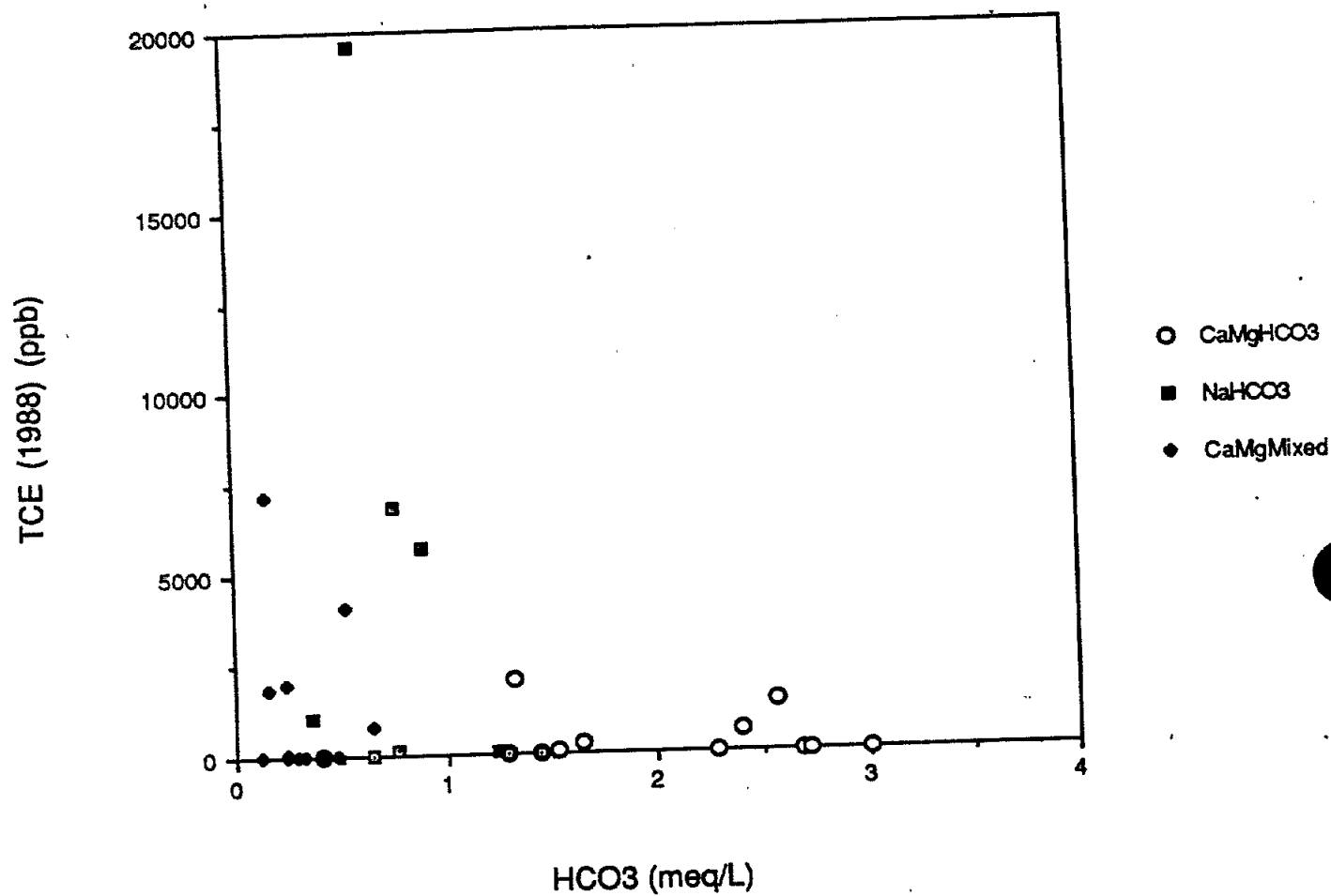
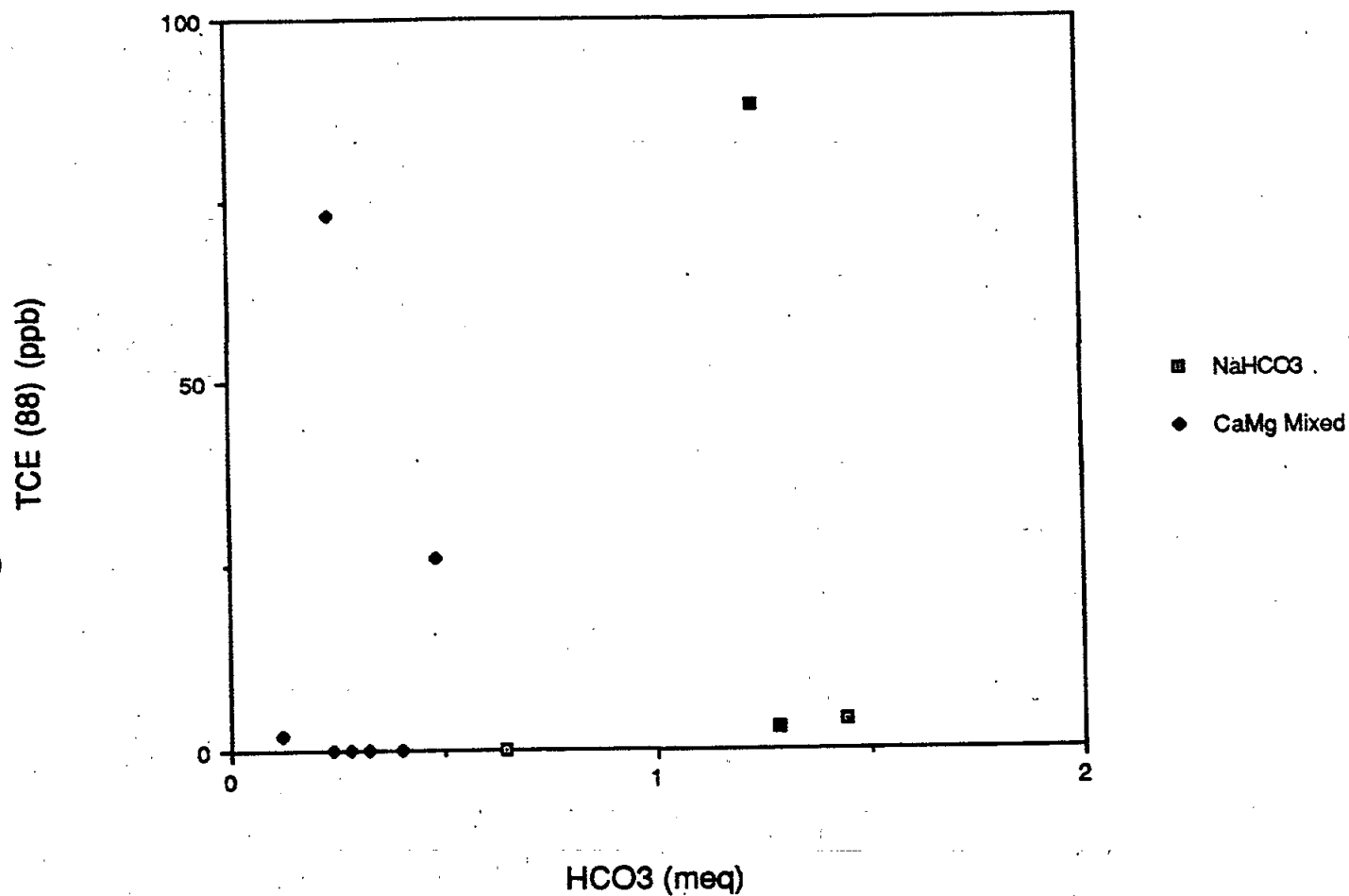
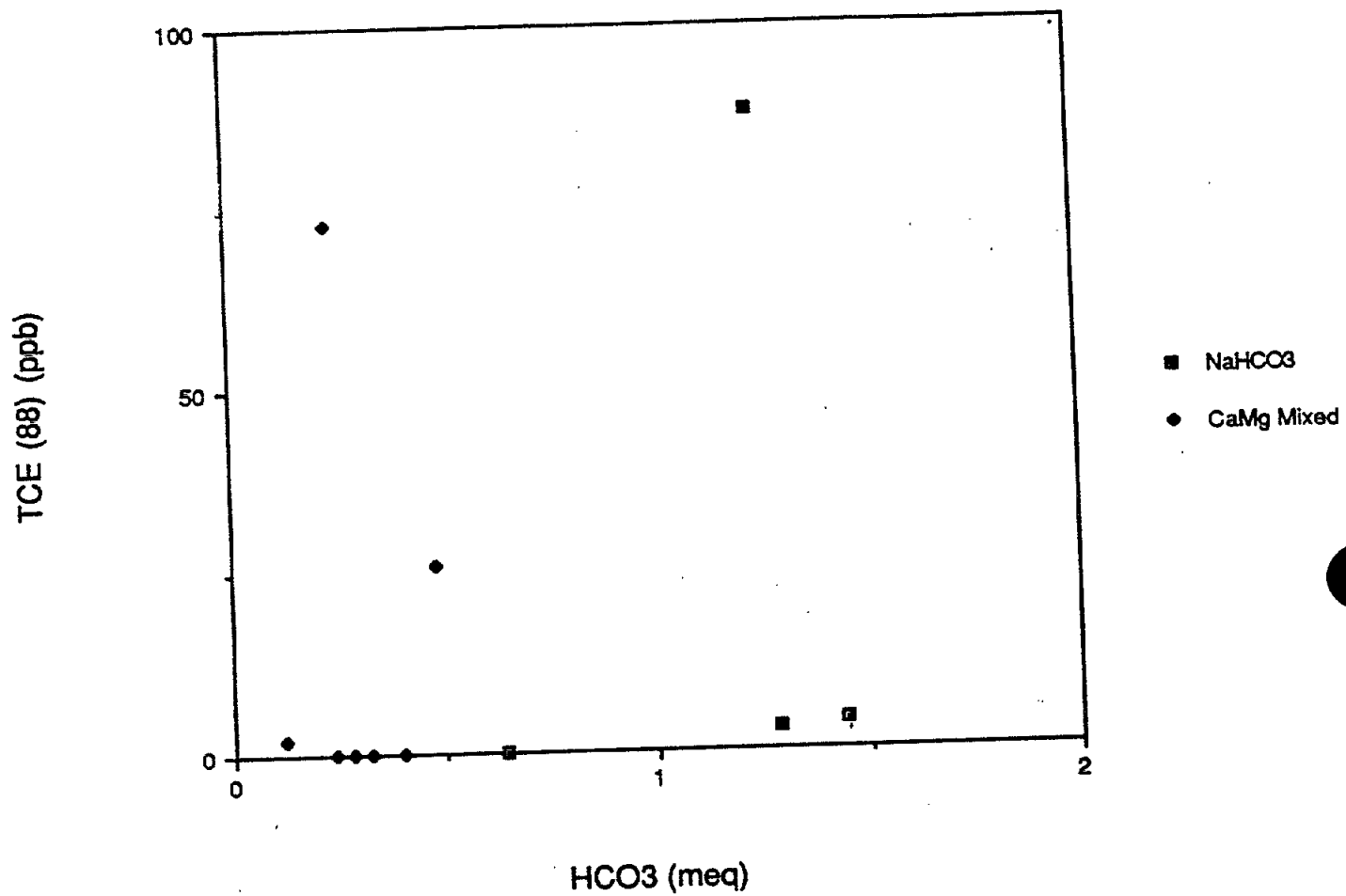


Figure 43. TCE versus  $\text{HCO}_3$  for  $\text{NaHCO}_3$  and CaMgMixed waters. TCE scale to 20,000 ppb.



AR300166

Figure 44. TCE versus HCO<sub>3</sub> for NaHCO<sub>3</sub> and CaMgMixed waters. TCE scale to 100 ppb.



## Hydrologic data

A plot of well elevation versus water table can be used to identify potential for downward or upward flow. Wells on top of a hill (e.g. Blackhead Hill) typically should have a deeper water table where there should be the potential for downward flow. Water levels in a valley should be shallower because of potential discharge. Conversely, water levels in high permeability rocks may be lower than water levels in low permeability rocks because the high permeability rocks act as a drain lowering water levels. Under water table situations this phenomena can be observed either as a comparison of water table to well elevation or by well elevation compared to depth of water in the well. Depths to Water in the overburden on Blackhead Hill may<sup>be</sup> shallower because of its impermeable nature or lower because of its general topographically high recharge position. Depth to water in the Tomstown limestone wells may be relatively shallow because of their low geographic position within the valley, that is, in the discharge zone or the depth to water may be greater because of higher permeability. The general trend of monitoring wells located in clusters (MW wells) is for a lower water table elevations in deeper bedrock wells than in shallower overburden wells(e.g., MW1, MW3, MW 4 and MW 6) (Table 4). This suggests the potential for downward flow, and more importantly, that the deeper holes are screened in formations with better permeability and better drainage. The shallower overburden wells, therefore, have lower permeability and less flow of water through them. This is in agreement with the observation of the

Weston/IT report that data from continuous water level recorders from bedrock well MW4R indicated unconfined water table conditions where as overburden well MW4OB showed confined conditions.

The water chemistry again plays an important role in separating different aquifers. In the case of of well clusters 4 and 6 (Table 4) the deeper wells appear to be screened in the limestones and have deeper water tables, where as the shallower wells are either in overburden or nonlimestone formations. For well cluster 7 where all the waters have Ca-Mg-HCO<sub>3</sub> compositions, the heads are the same. Limestone formations appear to have higher permeabilities.

Figure 45, a plot of water table elevation versus well elevation does not show a significant divergence of the different water chemistry types off a 1:1 slope. Na-HCO<sub>3</sub> waters are at the highest elevations, with the Ca-Mg-Mixed waters at intermediate elevations and the Ca-Mg-HCO<sub>3</sub> waters at the lowest elevations. The Ca-Mg-HCO<sub>3</sub> wells show a slightly deeper water table for the overall trend. Figure 46, a plot of well elevation to depth of water, shows a general trend of greater depth to water for the Ca-Mg-Mixed and Ca-Mg-HCO<sub>3</sub> waters than for the Na-HCO<sub>3</sub> waters, particularly considering that they are located at lower elevations where the water table should be shallower to land surface. This is definitely true for the Ca-Mg-HCO<sub>3</sub> waters. Water table elevations in the limestones appear to be at the elevation of Perkiomen Creek which suggests that the creek is the discharge for the limestone ground waters. If ground-water elevations are below the creek then the limestone would not



discharge to the creek and base flow to Perkiomen Creek would be maintained by discharge from the overburden material. This has implication as to how far TCE can flow within the limestone aquifer. TCE contaminated ground water should eventually discharge to the stream.

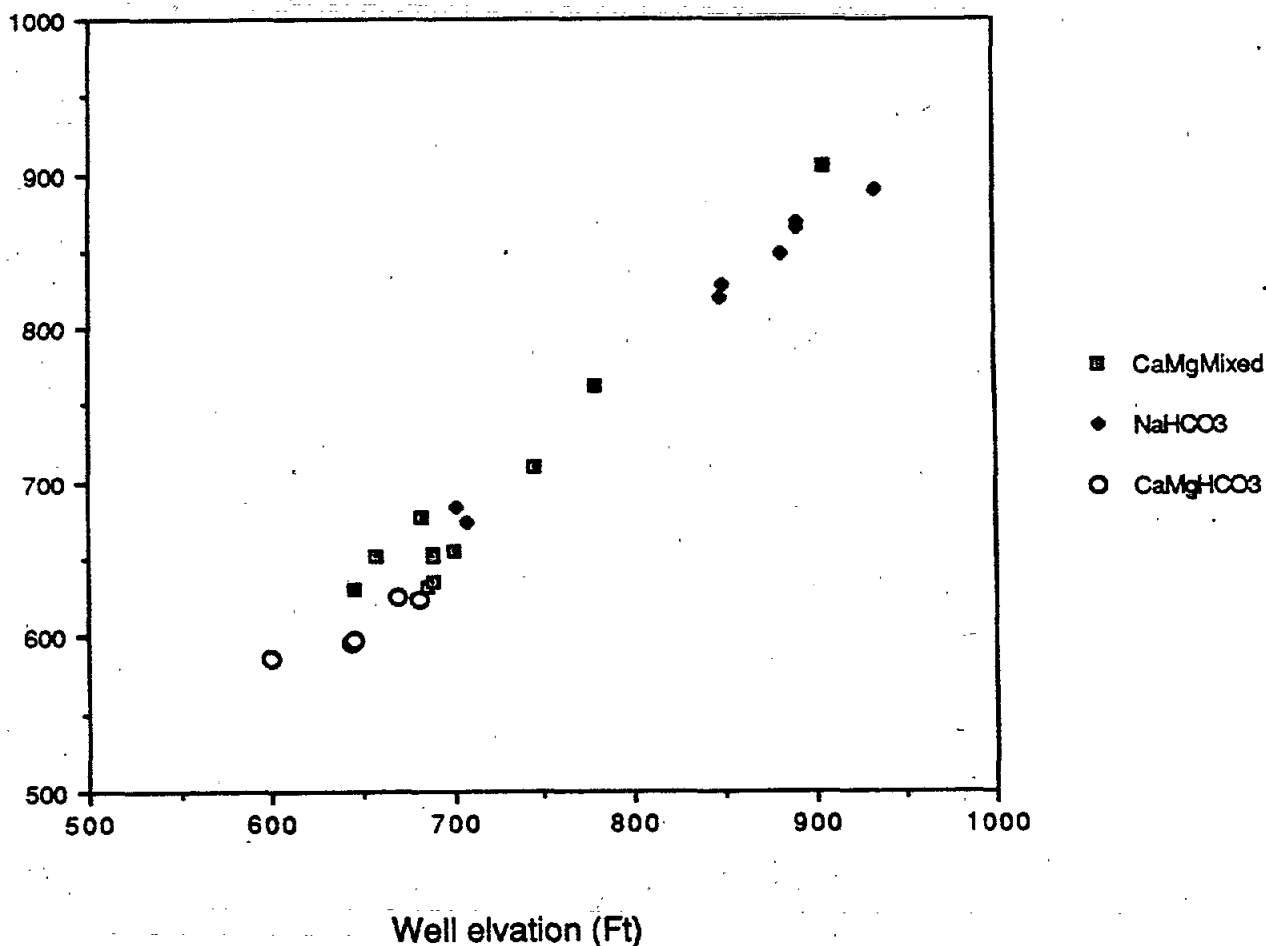
Water Table Data

	location	well elev	Well depth	DTW 6/88	DTW 7/88	WT 6/88	WT 7/88	Chemical Group	Geology
1	MW10B	850	56	22	28	828	822	Na-HCO3	bp
2	MW1R	849	162	29	35	820	814	Na-HCO3	bp
3									
4	MW2R	892	51	29	30	864	862	Ca-Mg-HCO3	bp
5	MW2DR	891	305	23	26	868	864	Na-HCO3	bp
6									
7	MW30B	702	23	18	21	683	681	Na-HCO3	bp
8	MW3DOB	707	70	34	37	673	669	Na-HCO3	bp
9									
10	MW40B	682	21	6	7	676	675	Ca-Mg-Mixed	Chm
11	MW4R	681	237	58	62	623	618	Ca-Mg-HCO3	Chm
12									
13	MW5DOB	689	103	53	58	636	631	Ca-Mg-Mixed	Chm, bp
14	MW5R	688	302	35	42	653	645	Ca-Mg-Mixed	Chm, bp
15									
16	MW60B	646	41	15	26	631	620	Ca-Mg-Mixed	OOc
17	MW6R	646	101	49	53	597	593	Ca-Mg-HCO3	OOc
18									
19	MW70B	645	56	48	52	597	593	Ca-Mg-HCO3	OOc
20	MW7R	644	95	48	52	596	592	Ca-Mg-HCO3	OOc
21	MW7DR	644	124	47	52	596	591	Ca-Mg-HCO3	OOc

AR300171

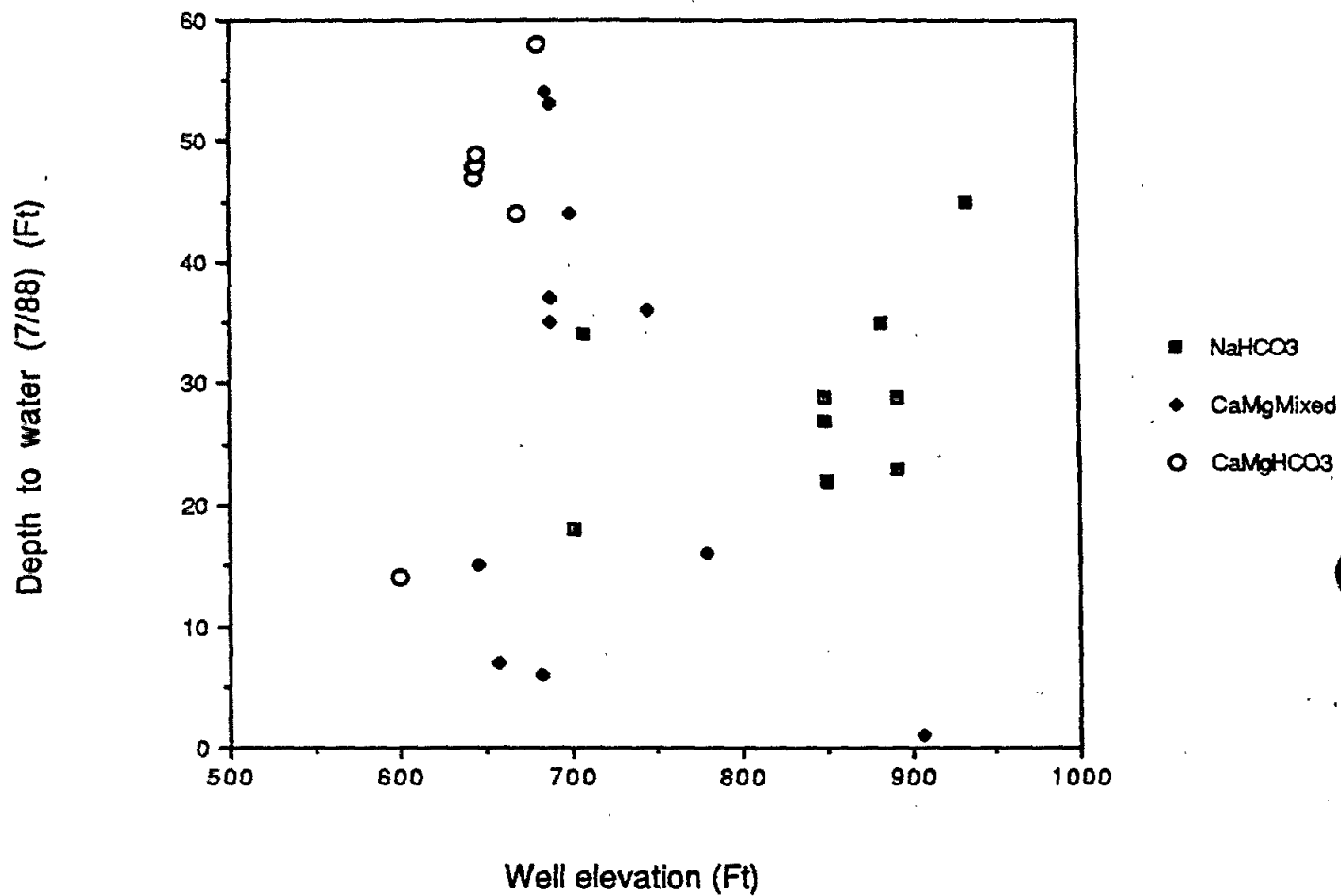
Figure 45. Well elevation versus water table for  $\text{NaHCO}_3$ ,  $\text{CaMgMixed}$ , and  $\text{CaMgHCO}_3$  waters

Water table (6/88) (Ft)



AR300172

Figure 46. Depth to water (7/88) versus well elevation for  $\text{NaHCO}_3$ ,  $\text{CaMgMixed}$  and  $\text{CaMgHCO}_3$  waters.



AR300173

## Discussion, Conclusions and Recommendations

Ground waters in the Hereford site, Berks County Pennsylvania, area have been contaminated by surface disposal of TCE on the Crossley Farm, located on Blackhead Hill. TCE ground-water contamination occurs in different rock types and shows up at appreciable distance (almost 2 miles away) from the suspected source. The contamination is not contained in a discrete definable plume as typically occurs in a porous media aquifer. The significant topographic relief, complex geology and possible fracture and fault zones has caused this extensive and complex spread of TCE.

Three different water chemistries, based on Schoeller diagrams have been observed. A Na-HCO<sub>3</sub> water occurs on Blackhead Hill from wells producing from Hardyston quartzite, the Byram gneiss and gneissic sapprolite. A Ca-Mg-Mixed water occurs in domestic water wells and a few monitoring wells in the valley at the base of Blackhead Hill. These wells also produce from the Byram gneiss, the Hardyston quartzite and overburden material. It is perplexing that the same rock types have different water chemistry. The third water chemistry group is a Ca-Mg-HCO<sub>3</sub> water that is produced predominantly from the Tomstown limestones. Each water chemistry group appears to be internally consistent, that is, a similar geochemical process can explain the evolution of the water chemistry within each group.

The chemical composition of each water type has also been used to evaluate whether one type of water has evolved from another water type that was hydrologically updip. Logically waters (Na-HCO<sub>3</sub>) from Blackhead Hill should flow down the topographic and

water table gradient to lower elevations and be evident in the chemistry of the Ca-Mg-Mixed and Ca-Mg-HCO<sub>3</sub> waters. The Ca-Mg-Mixed waters, however, cannot have evolved from the Na-HCO<sub>3</sub> waters. The TDS of the Ca-Mg-Mixed waters is less than the TDS of the Na-HCO<sub>3</sub> waters as well as having different chemical trends. With this chemistry it is hard to explain the movement of TCE from Blackhead Hill to surrounding wells at lower elevations. One option is that TCE may be moving as a separate phase and not part of the regional ground-water flow. A second option is that there are additional sources of contamination off Blackhead Hill. A third option is that well construction may have altered the water chemistry in the Na-HCO<sub>3</sub> well waters. These wells with Na-HCO<sub>3</sub> need to be repumped and reanalyzed.

The water chemistry of the Ca-Mg-HCO<sub>3</sub> waters strongly suggests that waters could have flowed from the Ca-Mg-Mixed waters into the carbonates. The chemistry does not support as well the flow of water from the Na-HCO<sub>3</sub> water to the Ca-Mg-HCO<sub>3</sub>. Establishing the flow system from the Byram gneiss and Hardyston quartzite to the Tomstown carbonate indicates that TCE contamination can migrate to the carbonate aquifers. An additional source of contamination is not needed to explain contamination in the limestones. The Tomstown limestones probably function as a hydrologic sink for the regional ground water flow in the area. High TCE concentrations will be diluted in the limestone by this regional flow.

The erratic distribution of TCE within the limestone and nonlimestone wells argues for fracture flow in the nonlimestone

Na can pass these suggestions along to remedial if they are interested.

formations and karstic flow within the limestones. The hydrogeologic setting for contaminant migration is a mixed fractured crystalline bedrock/ limestone karst system. Ground water may flow relatively rapid through fractures and caves. The strong topographic relief may result in relatively small flow systems. However, if the Herefords site is underlain by permeable Paleozoic carbonates, a larger flow system may occur and the areal extent of contamination may be larger. In that context, future contamination characterization studies and remediation strategies need to be oriented toward fracture/karst approaches. Much more detailed hydrogeologic characterization is needed.

#### Recommended additional characterization studies

1. Detailed geologic mapping. Detailed geologic mapping is needed to better characterize fractures and the complex geology. This should entail field mapping, aerial photograph interpretation for lineation patterns and surface geophysics to identify fracture zones.

2. Hydrogeologic characterization. Assuming ground water flow is within a mixed fractured bedrock/carbonate karst system, hydrogeologic investigation should be oriented toward approaches used in karst systems. Implicit in this type of ground-water system are relatively fast ground- water flow and short residence times.

Continuous water level recorders should be installed to measure how fast the aquifers respond to recharge events. If flow velocities are fast enough (Weston/ IT suggest a maximum flow velocity of 38 ft/day), artificial tracers, such as is used in small limestone karst aquifers, could be used to define discrete flow paths. Different

only in localized fracture zones

is this  
practical  
or even  
desirable  
such a  
rec?

tracers could be injected into the monitoring wells on Blackhead Hill. Activated charcoal or similar materials could be placed in the monitoring wells and contaminated wells to adsorb a tracer as it passed through the aquifer. Such a program would require a long term monitoring program. In this way major flow paths could be defined. Pump and treat programs could then be located. One logical location for pump and treat would be in the area of the intersection of Camp Mensch Hill Road and Forgedale Road, the area with the most contaminated domestic wells. There may be a fault zone between Blackhead Hill and this area providing a high permeability conduit. Tracer studies could be used to confirm. Because of the extreme heterogeneity of this system, detailed integrated hydrologic-geologic studies are needed. Numerical modeling is considered to be of limited value.

3. The presence of Na-HCO<sub>3</sub> ground waters complicates the hydrogeologic interpretation of the area. Water samples from the monitoring wells on Blackhead Hill should be recollected and analyzed for chemical composition to confirm the presence of the Na-HCO<sub>3</sub> waters. Field alkalinity should be measured through a longer purge than was done for the first sampling. The wells should be purged until alkalinity stabilizes. Correct pH measurements should be done in the field.

I believe  
our sampling  
SOP's to  
have been  
adequate.  
We have to  
look for  
another  
explanation



## References

Buckwalter, T.V. , 1959, Geology of the Precambrian and Hardyston Formation of the Boyertown Quadrangle. Pennsylvania Department of Internal Affairs, Topographic and Geologic Survey, Geologic Atlas of Pennsylvania, Atlas 197.

Buckwalter, T.V., 1962, The Precambrian of the Reading 15' Quadrangle. Pennsylvania. Pennsylvania Department of Internal Affairs, Topographic and Geologic Survey, Progress Report 161 (Fourth Series).

Piper, A.M., 1944, A graphical procedure in the geochemical interpretation of water analyses. Trans Amer. Geophys. Union v. 25, p. 914-923.

Schoeller, H., 1962, Les Eaux souterraines. Maison et Cie, Paris.

Weston/IT, 1988, Regional Hydrogeologic Investigation, Town of Hereford Site, Berks County, Pennsylvania, EPA contract No. 68-03-3482.